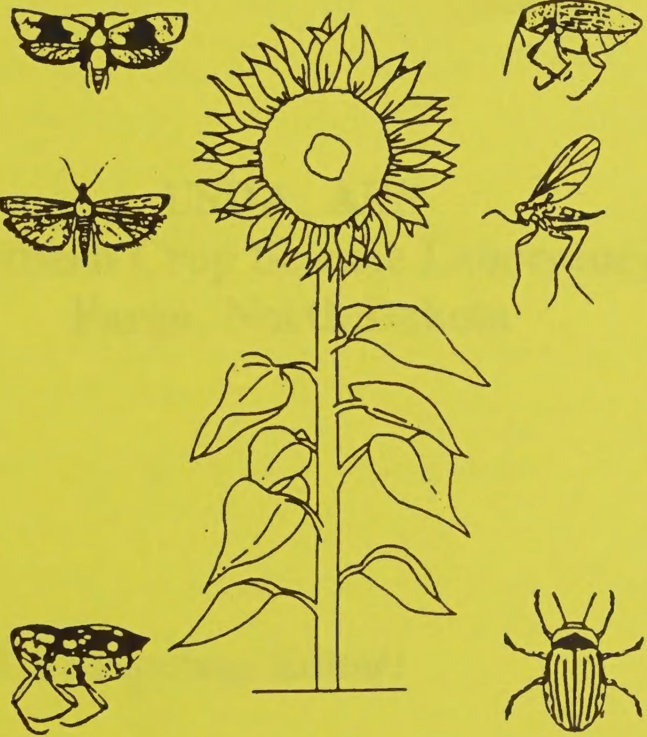
PROCEEDINGS

TENTH GREAT PLAINS SUNFLOWER INSECT WORKSHOP



APRIL 16 - 17, 1998 FARGO, NORTH DAKOTA

PROCEEDINGS

TENTH
GREAT PLAINS
SUNFLOWER INSECT
WORKSHOP

April 16-17, 1998

USDA, ARS
Northern Crop Science Laboratory
Fargo, North Dakota

Workshop Chair & Proceedings Editor:

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The Great Plains Sunflower Insect Workshop was developed to foster communication, exchange information, and develop solutions to insect problems of common interest. This volume contains the program, a list of participants and the presentations from the 1998 Workshop.

The papers in these proceedings are not to be used without the expressed permission of the authors.

Copies of the proceedings are available from the Workshop Chair

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10th Great Plains
Sunflower Insect Workshop
16-17 April 1998

U. S. Department of Agriculture, Agricultural Research Service
Northern Crop Science Laboratory
Fargo, North Dakota

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Program & Schedule

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8:40 - 9:00 ***Using bees to control pollinate sunflower in field cages*** *- Dick Wilson*, USDA, ARS, Plant Introduction Station, Iowa State University, Ames, IA

9:00 - 10:00 ***Insect Pest Problems in 1997 & Crop Loss Assessment*** *- Phil Glogoza*, Department of Entomology, North Dakota State University, Fargo, ND

Discussion

10:00 - 10:30 **Break & Refreshments**

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Discussion

11:30 - 12:00 **Conclusion of Workshop** - Formation of Interdisciplinary Sunflower IPM Working Group

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Sunflower Integrated Pest Management - Moving into the 21st Century: Introduction

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As we move into the next century it is important to review our current pest situation, what has been done in the past to manage insect population numbers, and what direction we should take in the future. If we take a global view and look at the competition we have for our food supply, the statistics are daunting to say the least. A total of 60,000 species of invertebrate pests and plant diseases and competition from 8,000 weed species are reported to cause a 40% loss of our agricultural products. However, without the use of current management measures, the losses were calculated to be at least 70% (Perrin 1997). We are holding our own, but we certainly have room for improvement. With an ever increasing world population it will be necessary to do an even better job of pest management in the future.

A few years ago the Clinton administration set out a challenge to have 75% of crop acreage under integrated pest management by the year 2000. A number of federal agencies, including the USDA, Agricultural Research Service, developed strategic plans to meet this challenge. Integrated pest management has also been the focus of most crop and animal management programs within entomology departments at most universities.

Integrated pest management (IPM) is an ecologically based pest control strategy that forms a part of the overall crop production system. Ideally, it incorporates all appropriate methods from many scientific disciplines into a systematic approach to minimize pest damage. Elements include the identification of the pest, use of economic or treatment thresholds, and a system to monitor the field to determine if the pest has reached the threshold. IPM control tactics include a variety of approaches, including cultural control, resistant plant varieties, biological control, as well as the use of insecticides. Successful IPM programs have been implemented for a number of crops because of an understanding of the crop agroecosystem based on years of research. However, in many crops, including sunflower, we have several pieces of the puzzle, but are still pursuing the goal of a truly integrated approach to pest management that works and is cost-effective (Zalom et al. 1992, Brown 1993, Charlet, 1995)

For a relatively recent crop, we have a good knowledge base of many of the insect pests that plague sunflower. We also have made strides in establishing economic thresholds and methods for monitoring the fields (Rogers 1992, Charlet and Barker 1995, Peng and Brewer 1995, Charlet et al. 1997, Peng et al. 1997). The papers contained in the proceedings review a number of IPM strategies including plant resistance, cultural control, and biological control. The future and potential of genetic engineering as a management tool are also discussed. A paper is also included which focuses on integrating what we do know and how we should be moving toward an integrated crop production system in which the management of insects is

developed in coordination with other disciplines such as weed control, plant breeding, plant pathology, and agronomy. An additional paper discusses the available opportunities for grants to investigate IPM strategies in utilizing different types of team approaches.

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Using Bees to Control Pollinate Sunflowers in Field Cages

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The U. S. National Plant Germplasm System's collection of sunflower, *Helianthus* spp., is maintained at the North Central Regional Plant Introduction Station in Ames, IA. The curator of the collection is Mary Brothers. Currently there are 1592 cultivated-type sunflowers in the collection with 1192 accessions available for distribution. There are 2119 wild-type sunflowers in the collection with 778 available for distribution. During 1997, there were 3343 seed requests, which represented 1396 of the 3811 sunflower accessions in our collection.

In order to multiply seed, all accessions were originally pollinated by hand. This is adequate for the cultivated types but is not an appropriate method for the wild types. This is because wild-type sunflowers have many, very small heads that are very difficult to hand pollinate.

Hand pollination begins by first preparing heads by stripping the ray flowers. Then pollen is collected within the accessions. The plants are pollinated by hand-rubbing pollen on with a "ghosty" and are bagged until harvest.

Cages need to be constructed for wild-type sunflowers. Here is the basic sequence: (1) lay out the pipe, (2) construct the frame, (3) cover the frame with netting, and (4) anchor the screen by shoveling soil around the base of the frame.

The original workhorse for cage pollination at the Plant Introduction Station was the honey bee. It is still used on many crops maintained at the Station. We use nucleus hives (nucs) containing about 4,000 - 5,000 bees plus a queen. We place around 700 - 800 nucs in field cages each year at the Station.

The worker bees are the 'bread and butter' of the hive. They live to take care of the queen. Each nuc has a queen. Without the queen, the workers will not do their jobs reliably. Honey bees are rather expensive to maintain because nucs must be constructed, queens must be purchased or reared, and considerable labor is needed to manipulate the hives.

For many crops, we place the nucs half-in/ half-out of the cage. This allows us to release the bees to the outside of the cage when there is not enough pollen and nectar to supply the bees from within the cage. We ran a pollen contamination study on sunflower a few years ago and found the bees will clean up extraneous pollen during a 12-hour period and thus, will not contaminate the germplasm we are trying to increase in the cage, if confined to their nucs overnight.

Wild type sunflowers produce many heads, and the bees usually have sufficient pollen and nectar to survive. However, we usually supplement with corn syrup and/or add a second nuc containing honey inside the cage to insure they have enough food.

Another type of bee we have tried to use is the bumblebee. They are excellent pollinators of sunflower and many other crops. They do present a problem because they are not easy to manage and they also sting.

Bumblebee queens are the only members of the colony that survive the winter. We collect them in the spring to begin rearing colonies for summer pollinations. In our rearing procedure, we provide pollen balls moistened with honey on which the queen lays her eggs. The pollen balls provide the offspring with food. The laboratory rearing procedure is not an easy one. Our main problem is when we try to mate the queens in the fall so they can begin a new colony the following year. We have had limited success with mating in the greenhouse. We haven't given up on our procedure, but most of our time is now spent on developing procedures for other bees that are easier to handle.

One such bee the alfalfa leafcutting bee. We buy cells from suppliers in Canada. The bees are widely used by large alfalfa production operations in the western U.S. Alfalfa leafcutters can be managed quite easily. They make their leaf cells in small holes drilled into wood blocks or preformed styrofoam. We place them inside pollination cages and they can do very nicely as an alternative pollinator to honey bees.

We are very excited about using a bee imported in 1977 from Japan by Susan Batra (USDA-ARS, Beltsville). This species, *Osmia cornifrons*, was imported for use on fruit trees and can be easily managed. They are excellent early-season pollinators of *Brassica* spp. at the Plant Introduction Station. We discovered we can hold the bees in a cooler and bring them out in the summer to pollinate warm-season crops. They successfully pollinate late-season crops, but in hot weather the bees die in about a week and won't reproduce.

Osmia bees need a mud supply to make their nests. That is why they are called mason bees. These bees construct about 7 - 8 cells in a straw. We use double straws in our rearing program. PVC pipe is used to construct domiciles for the bees. New, unused straws alongside straws containing bees from the previous season are placed inside the domiciles. When these domiciles are placed inside a field cage, the bees go about their business of pollinating.

We ran a comparison study to determine if we could use these alternatives to honey bees on sunflower. Replicated tests were run in field cages. For the two accessions tested, PI 586910 and PI 586934, honey bees were the best pollinators in 1995. In 1996, *Osmia* bees were as good as the honey bee for pollinating PI 586910. The bumblebee should have done better in our field studies, but I feel our colonies were not strong enough and *Osmia* bees worked best in cool weather.

A few years ago we tried to use the sunflower leafcutting bee for sunflower cage pollination. These bees are manageable because they nest in straws. We had difficulty increasing their numbers so they could be used the following year. This was partly due the presence of parasitic beetles. Another problem is that the bees won't use sunflower leaves to make their nests. We had to place *Oenothera* plants inside cages to provide nesting material. Now that we have some experience with *Osmia* bees, we would like to try the sunflower leafcutting bee again. Our original supply came from Utah, but they have had trouble getting us a starter supply.

Sunflower Insect Pest Problems in 1997 and Crop Loss Assessments

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Introduction

Several surveys have been conducted in the North Dakota-South Dakota-Minnesota region. The surveys have been both mail questionnaires and field surveys.

The mail surveys were conducted to assess pest problems and pesticide use in the region. These surveys include the sunflower production area of Kansas. Surveys were completed for the years 1990, 1991, 1992, 1994, and most recently 1997. In addition, statewide pesticide use surveys for the state of North Dakota were completed in 1992 and 1996. The state surveys established pesticide use patterns, but did not identify target pests for those applications.

A field survey was conducted in 1997 to estimate the extent of insect infestations, specifically the sunflower midge. The survey identified the highest concentrations of sunflower midge damaged fields through a simple classification scheme.

Grower Surveys

The grower surveys conducted in the past ten years have been useful for collecting information on pesticide use patterns and identifying key pest concerns. Recent surveys have included question items that address non-pesticide pest management practices, also. The most recent sunflower grower survey has expanded to include information relating to use rates of pesticides, target pest, and when applications occurred. This information is being requested in light of the 1996 Food Quality Protection Act. As pesticides undergo tolerance reviews under this legislation, assessments will consider use patterns where information is available. Without this information, the alternative assumption for an assessment is to assume a pesticide's usage on all labeled crops with application to every acre and a harvested product having the maximum allowable residue. An outcome from collecting this information is to develop a crop profile that lists the common pests, pesticides used to manage them, and the use patterns. This should allow for realistic assumptions to be used in assessments, and, if pesticide uses are targeted for cancellation, a method of determining a products importance and the likelihood of a replacement.

The following survey information is provided by H. A. Lamey and J. L. Luecke of North Dakota State University and represents part of the *1997 Sunflower Grower Survey of Pest*

Problems and Pesticide Usage in Kansas, Minnesota, North Dakota, and South Dakota currently under preparation. The project was funded through a regional Pesticide Impact Assessment Program (PIAP) grant. The objectives of the survey were: determine changes in pest problems and pesticide use since the 1994 survey; determine use patterns for pesticides to be reregistered or targeted for regulation, specifically Furadan, Eptam, Poast, Parathion, and Lorsban; determine changes in production practices; and, determine effect of changing production practices on pest problems.

Growers were surveyed by mail in the fall of 1997. Growers contacted by state were: Kansas, 2,400 (all available sunflower growers); Minnesota, 1,400 (all available sunflower growers); North Dakota, 2,364 (1/4 of the sunflower growers); South Dakota, 1,950 (3/4 of the sunflower growers). The grower contacts were made through the National Sunflower Association. The response rates and the acres represented by respondents were: Kansas, 103 (4.3%), 24,615 acres; Minnesota, 83 (5.9%), 22,646 acres; North Dakota, 261 (11.0%), 92,873 acres; South Dakota, 163 (8.4%), 76,460 acres.

Insect Problems and Pesticide Use

Insect problems identified by respondents varied by production region (Figure 1). In the Dakotas and Minnesota, the sunflower beetle was the most important insect problem. Growers in North Dakota and Minnesota listed the sunflower midge as a major problem. In South Dakota, the stem weevil and seed weevil were important pests. These two pests have been of less concern farther north the past four seasons. In Kansas, the sunflower head moth and stem weevil were the two most important insects. The responses agree with perceptions by university entomologists of which insects have been most important.

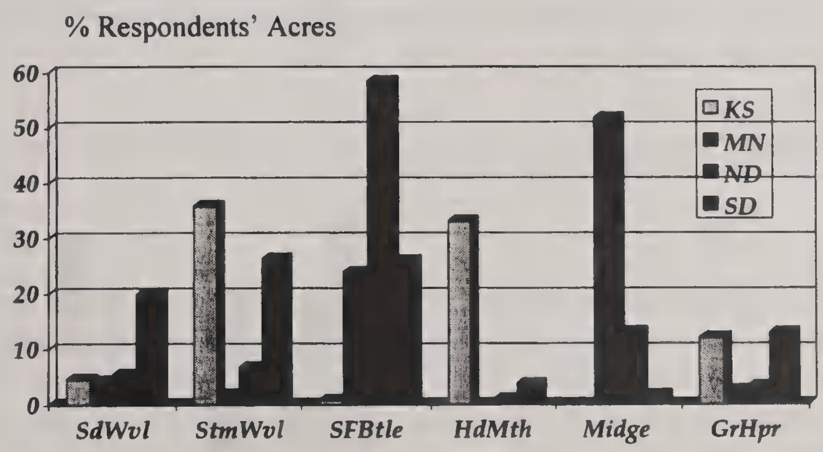

Figure 1. The worst insect problem reported by survey respondents by state (SdWvl = seed weevil, StmWvl = spotted stem weevil, SFBtle = sunflower beetle, HdMth = sunflower head moth, Midge = sunflower midge, GrHpr = grasshopper).

Other insects mentioned, by a smaller number of respondents as their worst problem, included the banded sunflower moth and cutworms. In North Dakota during the 1997 season, cutworms caused concerns in counties located in the Devils Lake region.

Insecticides used most frequently by respondents were Asana XL, Parathion, and Warrior (Figure 2). Asana and Warrior have been used extensively in North Dakota to control sunflower beetle. The parathion use in Kansas was directed at controlling sunflower head moth. Kansas growers have also used Asana, Furadan, and Warrior to control this pest. The sunflower head moth was the most frequently controlled insect by Kansas growers, and sunflower beetle was the most frequently controlled insect by North Dakota, Minnesota, and South Dakota growers (Figure 3). Other insecticides mentioned in the survey included Furadan, Lorsban, Baythroid, Scout X-tra, and Sevin. Other insects mentioned as targets for control were banded sunflower moth and the sunflower midge.

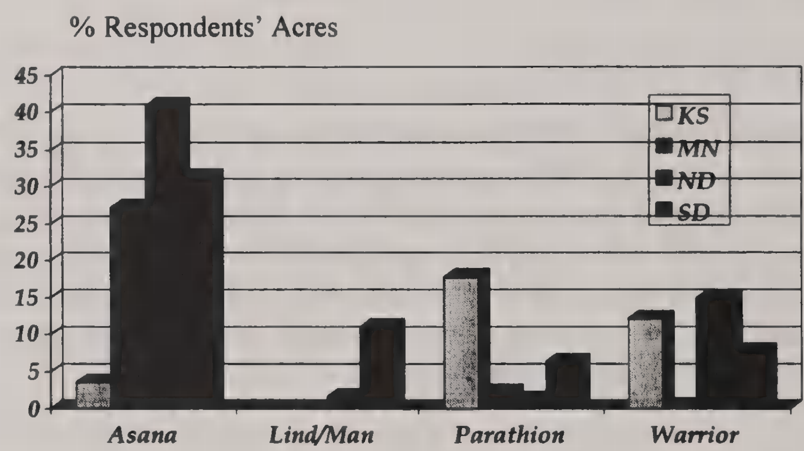

Figure 2. The most often reported insecticides used by survey respondents (Lind/Man = Lindane and Maneb used as seed treatment).

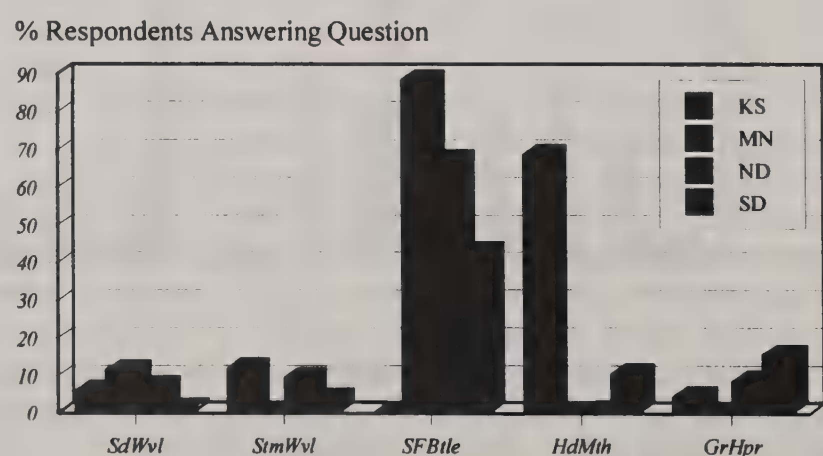

Figure 3. Insects targeted for control with insecticides by responding growers.

When looking at pesticide use patterns from the most recent years in the state of North Dakota, there has been a shift in pesticide classes used. The predominant group is the pyrethroids which include Asana XL, Warrior, Scout X-tra, and Baythroid (Table 1). These products have been very effective against the sunflower beetle larva. Since this has been the dominant insect problem in the state, it is not surprising to see this use trend. When the red seed weevil returns as a major production factor, it will be interesting to note whether growers and applicators resume more extensive use of the parathion products, long regarded as very effective against that pest.

Table 1. Insecticide use reported by survey respondents from 1996 and 1997 on sunflower acreage in North Dakota.

Insecticides	1996 North Dakota Pesticide Use [1] Acres Treated		1997 Sunflower Grower Survey [2] Respondents Acres Treated	
	(x 1000)	(%)	(x 1000)	(%)
Bacillus thuringiensis	1.4	0.1	---	---
Sevin	7.0	0.6	---	---
Furadan	14.4	1.2	1.3	1.4
Lorsban	2.6	0.2	0.2	0.2
Asana XL / Pydrin	290.3	24.6	38.8	41.8
Warrior	126.0	10.7	14.1	15.2
Malathion	1.7	0.1	---	---
All Parathions	19.3	1.6	0.8	0.9
Scout X-tra	10.4	0.9	---	---
All insecticides	473.0	40.1	55.2 [3]	59.5
Sample size =	10,000		2,364	
Usable responses =	4,000		254	
Sunflower growers =	640 (16%)		261	

[1] Zollinger et al. 1997.

[2] Lamey et al. 1998.

[3] Respondents acres treated represent 4.6% of the total North Dakota sunflower acres.

The sunflower midge is primarily an economic concern in the Red River Valley region of North Dakota, Minnesota, and Manitoba, Canada. During the mid-90's, significant outbreaks within the region have occurred, with the center of the outbreak shifting from season to season. The shift may be due to the reluctance of growers to grow sunflower the following year after an outbreak that produces economic losses. Without sunflowers grown following an outbreak, midge would be expected to migrate more readily in search of flowers creating problems near, but away from the problems of the previous season. Another factor that contributes is the above normal rainfall patterns during these years. A field survey conducted in 1997 identified the areas of western Cass and eastern Barnes Counties of North Dakota as having significant infestations and injury due to the sunflower midge (Figure 4). These areas

had rainfall accumulations during the last two weeks of June with a ranging from 4 to 7 inches. Precipitation is one major environmental factor that contributes to midge outbreaks.

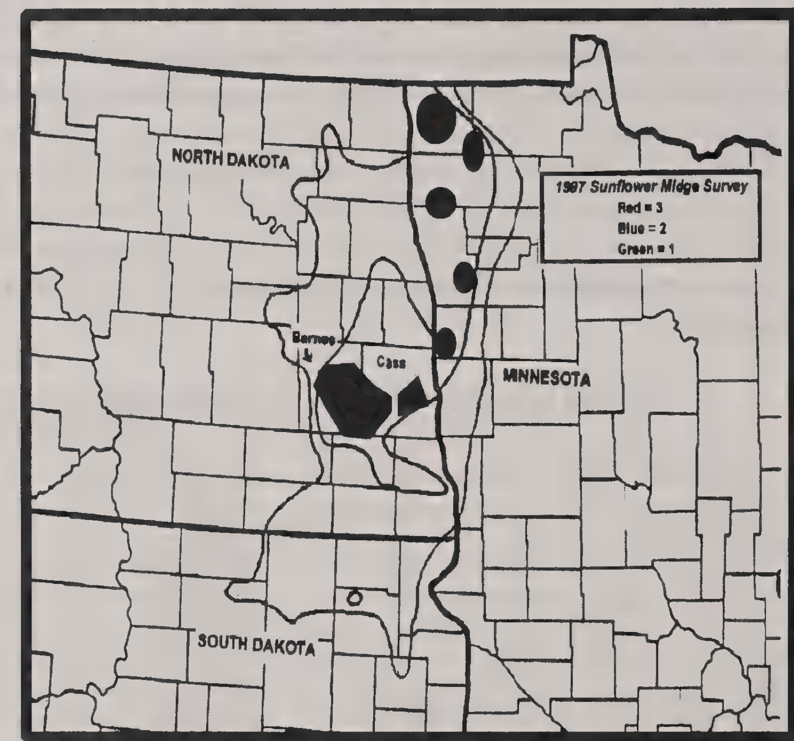

Figure 4. Sunflower midge infestation levels observed in the Red River Valley region during the 1997 season. Shaded areas represent a field infestation rating of 1 = midge injury throughout the field; the black line represents areas where fields had damage ratings of 2 = midge injury on field margins; and, the gray line represents areas where fields had damage ratings of 3 = midge present at low levels. (Source: Gary Brewer, Department of Entomology, NDSU, and Larry Charlet, USDA-ARS, Fargo, ND)

Crop Loss Assessment

There have been no regular surveys designed to assess yield loss in sunflowers resulting from infestations by insect pests. The 1997 sunflower midge survey is the closest formal effort to look at pest injury to this crop. Most of the annual summaries of insect pest occurrence and their impact are based on expert opinion. The experts have been sunflower growers, county agricultural extension agents, state extension specialists, and university researchers. The focus of gathering these opinions has been to document which insects were present at significant levels during the current growing season. This information is used to establish educational programming priorities for the next growing season. This type of survey

effort is known as an indirect method. Indirect methods have the greatest potential for gathering information over the largest area, while completing it in the shortest amount of time.

Direct methods would involve planned field surveys. In general, they require a significant commitment of people's time. These efforts often are implemented when major pest problems occur, such as with the sunflower midge survey conducted in 1997.

Selected References

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Sunflower Integrated Pest Management: Cultural Control

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Cultural control, typically one approach of integrated pest management (IPM), includes tactics that incorporate low input costs and avoid negative impacts to the environment. Cultural controls are methods basic to farming since they usually use farming practices already associated with crop production. They act to make the environment less favorable to the pest through reduced reproduction or growth. Cultural control techniques prevent the buildup of damaging populations of the pest rather than relieve an existing problem. Thus, they need to be employed long before the pest or pest induced damage is apparent in order to be effective. It is often necessary to direct the tactic against non-pest stages of the insect. Cultural controls are not always used alone, but are frequently combined with other IPM strategies (National Academy Science 1969, Charlet 1996). Sometimes they are more effective if applied over a large area to reduce pest populations and also to prevent their reintroduction. Research has shown that the concept of Areawide Pest Management has been shown to be effective and is beginning to be used for the management of a variety of pests including those of cotton, apples, pears, and corn (Faust 1997).

The use of cultural controls has a number of advantages along with a few problems associated with their implementation. On the plus side, because they use basic farming practices these tactics usually do not require additional costs for equipment. There are no detrimental side effects which are often associated with the use of pesticides, and cultural controls are simple, effective, and inexpensive to apply. However, there are some disadvantages to the effective use of cultural controls and these include the fact that they usually must be applied early, before the producer knows whether a problem will occur or not. The control is not always complete with these tactics and detailed knowledge of the pest and its biology is required to insure that the methods will be as effective as possible.

There are a number of different tactics included within the IPM method of cultural control. Some of these include sanitation, crop rotation, tillage, changes in planting date, plant spacing or plant population, and trap cropping. Examples of each of these in relation to management of sunflower pests will be discussed.

Sanitation

Sanitation may benefit the producer in the management of a number of important pests. Although research has not been conducted in sunflower, studies in a variety of crops has shown that the prevention or cleanup of weedy areas within the field may reduce the damage caused by cutworms and wireworms by removing areas where the insects lay their eggs, breeding locations, or overwintering sites. The destruction of crop refuse or debris has also

been shown to decrease populations of some species of cutworms. The elimination of weeds and wild host plants on field margins aids in the reduction of pest numbers by removing locations where the pest can feed and reproduce. Keeping the field margins clean may also help by eliminating hosts of plant pathogens and their vectors. However, the margins and certain flowering weed species have also been shown to be a source of pollinators as well as beneficial predators and parasitoids that often use these plants as sources for nectar and habitat for alternative prey. The natural enemies congregate in these sites before moving into the field to attack the crop pests. The downside of weed-free field and borders must also be weighed against potential soil and water erosion and soil moisture loss (National Academy Science 1969, Davidson and Lyon 1987, Glogoza 1998).

Crop Rotation

The rotation of crops, while used for years because of nutrient and moisture concerns, also can have an impact on pest populations. It is most effective against insects with restricted host ranges or limited movement. Sunflower pests fit these parameters because they are native insects attacking a crop derived from a native plant (*Helianthus annuus* L.). They tend to be restricted to species of *Helianthus* or closely related plants. We currently have only limited information on the flight ability of most of the sunflower insect pests, so we cannot accurately determine the optimal distance between fields to reduce movement of the pests. However, locating a sunflower field at some distance from the previous year's field may at least lessen the infestation.

The consequences of application of this tactic has not been reported for most sunflower pests. However, Westdal and Barrett (1955) noted that in Canada populations of the banded sunflower moth, *Cochylis hospes* Walsingham, were reduced the subsequent year when fields were seeded at a distance from the previous year's crop. The separation of the pest from the crop by time or space is effective because it eliminates the host plant used by the insect for either feeding or for egg laying.

Tillage

Insects are affected by soil texture, moisture, temperature, microorganisms, and the effects of these on their food. The tillage or cultivation of the soil can act on these different factors to impact insects which spend a portion of their life history on or in the soil environment. One of the keys to the effective use of tillage is timing that takes advantage of weak links in the life cycle of the pest. In order to do this, knowledge of the insect's life history and habits is required. Cultivation of the soil may act to bury the pest so that it cannot emerge or alternatively to bring the pest to the soil surface to be destroyed by predators or dry or cold weather (Davidson and Lyon 1987).

Cultivation has been attempted against a number of sunflower insect pests. Stalks were not broken up enough by tillage equipment to kill sunflower stem weevil, *Cylindrocopturus adspersus* (LeConte), larvae overwintering within the stem tissue, but burial was found to reduce emergence of adults the following spring (Rogers et al. 1983, Charlet 1994). Tillage

was also effective against two other sunflower pests. Westdal and Barrett (1955) noted that fall plowing reduced banded sunflower moth emergence by 80% in sunflower fields in Canada. Both fall and spring plowing was effective in reducing red sunflower seed weevil, *Smicronyx fulvus* LeConte, emergence between 29-56% in South Dakota (Gednalske and Walgenbach 1984). Cultivation of the soil also may destroy grasshopper eggs or prevent them from being deposited since a number of species avoid cultivated soil. A combination of fallow and cultivation every 2-3 years eliminates food plants for wireworms, often reducing larval populations of these pests to non-economic levels (Davidson and Lyon 1987, Glogoza 1998).

Planting Date

The manipulation of planting date as a cultural control tactic is based on either growing the crop when the pest is not present or seeding the crop so that the most susceptible stage of the plant coincides with a time of the year when the pest is least abundant. It is a fairly easy strategy to implement, but as with many other cultural control methods it requires knowledge of the biology and habits of the insect pests that are to be managed. The advantages of altering the planting date need to also be weighed against the agronomic implications for the crop. In addition, the options for changing seeding dates either earlier or later in the season are greater in southern regions with longer growing seasons, but reduced in areas with short seasons.

The altering of the planting date has been shown to be an effective method in reducing damage by a number of sunflower pests. Delayed planting was effective in reducing insect damage, without loss in seed weight or oil content, from the banded sunflower moth, sunflower stem weevil, sunflower moth (*Homeosoma electellum* (Hulst)), and the sunflower midge (*Contarinia schulzi* Gagne) (Teetes and Randolph 1971, Mitchell et al. 1978, Oseto et al. 1982, Rogers et al. 1983, Oseto et al. 1989, Glogoza et al. 1997). In the case of the sunflower midge, later planting dates have not always been successful in reducing damage from this insect and the better option has been to seed plantings at a variety of dates so that all fields do not reach the vulnerable stage (bud stage) at the same time. In contrast to most of the important sunflower insect pests, early planting dates prevented economic seed damage by the red sunflower seed weevil (Oseto et al. 1987). Thus, the potential pest situation for the current season needs to be weighed against results from the previous year in arriving at a decision on the optimal time to plant the crop and avoid losses from specific sunflower pests.

Plant Spacing or Plant Population

The plant spacing or plant population of the crop may also influence the pest population and the damage they cause to the plants. This can occur by either affecting the relative growth of the plants or the pest population itself. The plant density or spacing may influence the behavior of the pest in searching for food or oviposition sites. Natural enemies of the particular insect pest may also be affected through their ability to locate and effectively attack the host.

The impact of altering plant population has not been studied for most of the major sunflower pests. But, the influence of changing within-row plant spacing (6, 12, 24 inch) was investigated for the sunflower stem weevil (Charlet and Brewer 1994). Larval stalk density was not affected

by the plant density within the plots, but stalk diameter was significantly different among all three plant populations, with the thinnest stalks in the most dense planting. Although insect density was not affected, the lodging due to weevil larvae in the stalks resulted in almost 25% of the plants being lodged at the highest plant population. Another impact of altering the plant population could be the influence on insect sampling designs and economic thresholds. These might have to be revised if plant densities change more than a certain percentage from the norm, but research would need to be conducted to determine the effects.

Trap Cropping

The idea of trap cropping is to lure the pest from the main crop to a smaller area where they can be more easily controlled. Thus, the insect is hopefully prevented from moving into the crop being protected. It is a special form of intercropping which has in the past been used to improve the yield or quality of a crop by the interaction among the crops (National Academy Science 1969). The method has been shown to be a promising tactic against the red sunflower seed weevil (Brewer and Schmidt 1995). The main sunflower field is surrounded with a border containing an early maturing hybrid seeded so that it will bloom 7-10 days earlier than the main field. The adult red sunflower seed weevils are attracted to blooming sunflower heads and thus are attracted and concentrated in the earlier maturing trap border where they can be treated if necessary. This method reduces the producer's overall costs since, if treatments are needed, only the border (about 10% of the field) would have to be sprayed.

Conclusions

The use of cultural control strategies to manage insect pests has the advantage of being a group of techniques that modify the timing or the manner of performing necessary functions in the production of a crop. These strategies require a thorough knowledge of the insect based on biological research into its life history and its interaction with crop growth and the environment. The results are not always dramatic, but reductions in pest numbers by using cultural control practices may delay the pest's rise to economic levels and thus save the added expense of chemical treatments. An added benefit is the fact that cultural controls are compatible with many other IPM practices in the management of insect pests in the crop agroecosystem.

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Sunflower Integrated Pest Management - Biological Control: Predators and Parasitoids

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Integrated pest management (IPM) is an ecologically based pest control strategy that forms a part of the overall crop production system. Ideally, it incorporates all appropriate methods from many scientific disciplines into a systematic approach to minimize pest damage. IPM control tactics include a variety of approaches including cultural control, resistant plant varieties, chemical control, and biological control. The use of biological control is a fundamental tactic for suppression of pests within an effective IPM program. The definition of biological control varies from author to author, but it essentially refers to the use of natural enemies against a pest population to reduce the insect's density and damage to a level lower than there would be in their absence. The natural enemies of insect pests fall basically into three types. The predators include lady beetles, ground beetles, syrphids, lacewings, and predaceous bugs. The immature stages are mobile, they usually consume more than one host during their development, are often generalist feeders (more than one species of host attacked), and often both the adults and immatures feed on the host insect. In contrast to predators, parasitoid adults are free-living, the immature stage lives on or inside a single host and kills the host before completing development. Parasitoids are often specific to one or at least closely related species of host insects. Parasitoids are usually members of the order Hymenoptera or wasps and a few are members of the order Diptera or flies. Pathogens are disease causing organisms that include viruses, fungi, bacteria, protozoans, and nematodes. The action of these latter natural enemies in relation to sunflower insect pests are discussed in another proceedings paper.

The use of biological control to manage pests is divided into three types of approaches. Importation refers to the search for better natural enemies to introduce and permanently establish. The need for importation biological control occurs when a pest is accidentally introduced into an area and its natural enemies are left behind. An attempt is made to locate these enemies and introduce them to reestablish the control that often existed in the native range of the pest. This may be from another country or in some cases, another region of the same country. In augmentation, an attempt is made to reduce a pest's population to non-economic levels by temporarily increasing natural enemy numbers through periodic releases. In some cropping systems, technology has been developed to rear natural enemies artificially so that these releases can be made economically. A number of commercial companies have been created to produce a wide variety of natural enemies, both predators and parasitoids. The last method or approach to biological control is conservation. In conservation, an attempt is made to manipulate the environment or the farming practices to protect the natural enemies or provide needed resources (e.g. food for adults or alternate prey) for them to survive and build up populations to levels where they can manage the pest and prevent it from causing economic

damage to the crop.

Biological control as a management tool dates back over 1,000 years. Ancient China citrus growers used ants to control caterpillar larvae infesting their trees. It is one of the safest methods of control since it is not toxic, pathogenic or injurious to humans. Biological control has the advantage of being self-perpetuating once established and usually does not harm nontarget organisms found in the environment. In addition, it is not polluting or as disruptive to the environment as chemical pesticides, nor does it leave residues on food, a concern to many people today. However, the use of biological control does require detailed knowledge of the pest's biology and population dynamics, as well as the natural enemies associated with the pest and their impact. Control is usually not complete with this IPM method since a residual population of the pest is necessary for the natural enemies to remain in the environment. Thus, some damage to the crop must be acceptable or tolerated. Biological control also fits well in combination with other IPM strategies (Charlet and Brewer 1996).

Predators

Investigations into the action of different predators and their impact on sunflower pests has been limited. No predators have been reported in the literature to attack either the **sunflower stem weevil**, *Cylindrocopturus adspersus* (LeConte) or the **sunflower midge**, *Contarinia schulzi* Gagne. However, this is probably due to a lack of research rather than an absence of predators. A number of generalist insect, as well as spider, predators are present in the sunflower agroecosystem and probably feed on both pest species.

The larvae and pupae of the **red sunflower seed weevil**, *Smicronyx fulvus* LeConte, overwinter in the soil and were reported to be attacked by three different predators in North Dakota. Pinkham and Oseto (1987) noted that larvae of two species of predaceous flies in the family Therevidae, *Thereva candidata* Loew and *Fucifera rufiventris* Loew, consumed both larvae and pupae. In addition, ants of the species *Formica cinera montana* Emery also attacked and consumed the overwintering seed weevil in the soil.

Predation of the **banded sunflower moth**, *Cochylis hospes* Walsingham, was considered to be an important factor in reducing populations of this sunflower pest based on a life table study conducted from 1986 to 1988 (Bergmann and Oseto 1990). Eggs and larvae were consumed by the predators, *Orius tristicolor* (White) (Anthocoridae), *Nabis rosipennis* Reuter (Nabidae), *Chrysoperla carnea* Stephens (Chrysopidae), and a number of species of lady beetles (*Hippodamia* spp.; Coccinellidae). Larvae feeding in the seeds were also consumed by redwinged blackbirds, *Agelius phoenicus* L., while the birds were feeding on sunflower achenes. A number of species of predaceous ground beetles were present in the fields and probably consumed overwintering larvae. Analysis of gut contents of a number of the beetles showed that *Pterostychus lucublandus* Say (Carabidae) had attacked and fed on banded sunflower moth larvae (Bergmann and Oseto 1990).

Pupae and larvae of the **sunflower moth**, *Homeosoma electellum* (Hulst), were reported to be consumed by the clerid beetle, *Phyllobaenus pubescens* (LeConte) in Missouri (Satterthwait

1948). Seiler et al. (1987) observed the crab spider, *Misumenops* sp. (Thomisidae), on several occasions feeding on both larvae and adult sunflower moths in sunflower fields in the Texas High Plains. A large number of insect species were noted to be predators of sunflower moth larvae in Mexico including the coccinellids, *Hippodamia convergens* Guerin-Meneville and *Coleomegilla maculata* (De Geer), *Collops vittatus* Say (Melyridae), *Orius insidiosus* (Say) (Anthocoridae), *Geocoris punctipes* (Say) (Lygaeidae), *Nabis* sp. (Nabidae), *C. carnea*, and the reduviids, *Zelus exsanguis* (Stal) and *Sinea* sp. (Tejada and Blanc 1976).

Based on a multiple year study of the **sunflower beetle** in Manitoba, Canada, a number of predators were determined to be feeding on the different life stages of the sunflower beetle, *Zygogramma exclamationis* (Fabricius) (Neill 1982). Adult beetles were attacked by redwinged blackbirds and the stinkbug, *Podius maculiventris* (Say) (Pentatomidae). I have also noted the latter species attacking larvae in North Dakota sunflower fields. Sunflower beetle eggs were consumed by the melyrid beetle, *Collops vittatus* Say, and the lady beetles, *Hippodamia tredecimpunctata tibialis* (Say) (Coccinellidae) and *H. convergens* and *C. carnea* consumed both eggs and larvae. Rogers (1980) and Neill (1982) reported that sunflower beetle larvae were fed on by *Perillus biocolatus* (Fabricius) (Pentatomidae). In North Dakota, I have recovered a related species (*Perillus circumcinctus* Stal) in sunflower fields, although collections have been rare. The carabid beetle, *Lebia atriventris* Say, was reported to feed on sunflower beetle larvae in Manitoba (Westdal 1975, Neill 1982) and Texas (Rogers 1980). It appears to be a common inhabitant of sunflower fields in North Dakota and Minnesota and I have found it to be a voracious feeder of sunflower beetle larvae in the laboratory. Neill (1982) also noted that *Nabis* sp. was the fourth most common predator in sunflower fields in Manitoba and was suspected of feeding on sunflower beetle larvae.

Parasitoids

The **sunflower stem weevil** is parasitized by a number of wasp species. *Anaphes pallipes* (Ashmead) (Hymenoptera: Mymaridae) was reared from eggs of the weevil (Charlet and Balsbaugh 1984). Larvae are attacked by the following Hymenoptera in the northern Great Plains: *Nealiolus curculionis* (Fitch) (Braconidae); *Tetrastichus ainsliei* Gahan (Eulophidae); and *Mesopolobus* sp. (Pteromalidae) (Casals-Bustos 1976, Charlet 1983b). Rogers (1980) and Rogers and Serda (1982) reported two species of parasitoids from the weevil in Texas: *N. curculionis* and *Neocatolaccus tylodermae* (Ashmead) (Pteromalidae). Museum records report *Rhaconotus cressoni* Muesebeck and Walkley (Braconidae), *Eupelmus cushmani* (Crawford), and *E. cyaniceps* (Ashmead) (Eupelmidae) attacking larvae of the weevil (Krombein et al. 1979).

Nealiolus curculionis represented over 96% of the parasitoids attacking sunflower stem weevil larvae from 1980 to 1991 in North Dakota and is a consistent mortality factor even when the weevil density is low (Charlet 1994b). Parasitization of overwintering sunflower stem weevil larvae varied from 5 to 32% from 1980 to 1991. Results indicate that overall parasitization of *C. adspersus* has increased from levels that had been reported in the late 1970s and early 1980s. Except for 1989, and from 1986 to 1988 when no data were available, parasitism of stem weevil larvae by *N. curculionis* has averaged 27% since 1983, while the stem weevil

density has varied from 6 to 29 larvae per stalk. The rate of parasitism showed an increase from 1981 to 1983 as mean populations of weevil larvae decreased from 108 to 24 larvae per stalk (Charlet 1994b). *Nealiolus curculionis* is the only parasitoid species found attacking sunflower stem weevil larvae in native *H. annuus*. In eastern North Dakota and western Minnesota, about 19% of the stem weevil larvae in *H. annuus* from three locations were parasitized. Parasitoids were not recovered from weevil larvae in stalks of *H. petiolaris* Nuttall, *H. maximiliani* Schrader, or *H. tuberosus* L, probably because of the small populations of host larvae in the plants (Charlet et al. 1992). Studies of four species of native sunflowers in western North Dakota yielded larvae of the sunflower stem weevil in *H. annuus*, *H. petiolaris*, and *H. maximiliani*, and 16 adult parasitoids reared from the larvae in these plants were identified as *N. curculionis* (Charlet 1983a).

The parasitoids of the **sunflower midge** are largely unknown. The only reference in the literature is to an undescribed wasp species of *Inostemma* from the family Platygastridae (Sammuelson 1976). The impact of this larval parasitoid has not been studied. I have reared this same parasitoid species from overwintering sunflower midge larvae as well as an additional undetermined species of chalcid wasp.

Larvae of the **red sunflower seed weevil** have been reported as hosts for a number of parasitoid species. Cockerell (1915) found two species of Torymidae on sunflower in Colorado, *Torymus capillaceus albitarsis* (Huber) and *Zaglyptonotus schwarzi* Crawford, that he assumed were parasitizing *S. fulvus*. He further speculated that these two species might be suitable candidates to be introduced to Illinois where the weevil was causing economic losses in cultivated sunflower. In a series of papers Bigger (1930, 1931, 1932, 1933) reported rearing a number of parasitoids from the red sunflower seed weevil in Illinois. These included *Eupelmus amicus* Girault (Eupelmidae), *Bracon mellitor* Say (Braconidae), *Trimeromicrus maculatus* Gahan, *Zatropis incertus* (Ashmead) (Pteromalidae), *Torymus capillaceus albitarsis* (Huber) (Torymidae), and *Eurytoma* sp. (Eurytomidae). Parasitoids known to attack the red sunflower seed weevil in cultivated sunflower in North Dakota include: *Trimeromicrus* sp. (Oseto & Braness 1979), *Pteromalus* sp. (Pteromalidae) (unpublished data) and three species of braconids, *Bracon mellitor* (Oseto & Braness 1979), *Nealiolus curculionis* (Fitch) (Oseto & Braness 1979, Pinkham & Oseto 1987) and *Triaspis aequoris* Martin (Charlet 1994a, Charlet and Seiler 1994). Although *N. curculionis* was reported to be the only species attacking the red sunflower seed weevil in cultivated sunflower in the early 1980s by Pinkham and Oseto (1987), collections from the late 1980s to the mid 1990s did not include this parasitoid. As noted earlier, *N. curculionis* is a primary parasitoid of the sunflower stem weevil. During the 1980s to mid-1990s, except for a few specimens of an undetermined *Pteromalus* sp., I have only reared *T. aequoris* from overwintering larvae of the red sunflower seed weevil (Charlet 1994a). Dissection of red sunflower seed weevil larvae collected from cultivated sunflower at Prosper, North Dakota, from 1988 to 1993 showed an increase in parasitism by *T. aequoris* from 4 to 50%. The parasitoid female deposits eggs singly in weevil eggs and early instar larvae (Charlet 1994a).

The parasitoid fauna attacking the larvae of red and gray sunflower seed weevils, *S. sordidus* LeConte, in native *Helianthus* also has been investigated. Collections of *S. fulvus* larvae from

H. annuus in southeastern North Dakota yielded two species of pteromalid parasitoids, *Mesopolobus* sp. and *T. maculatus* (unpublished data). The latter species also had been recovered by Oseto and Braness (1979) from cultivated sunflower. Charlet and Seiler (1994) recovered a total of five species of endoparasitoids from overwintering red and gray sunflower seed weevil larvae from different sunflower species in South Dakota, Kansas, Nebraska, Wyoming, Colorado, Montana, and North Dakota. Larvae of both red and gray seed weevils occurred together, but since they could not be identified to species, host specificity of species of parasitoids was not delineated. The following species of braconid wasps were recovered: *T. aequoris* in larvae from *H. annuus* and *H. petiolaris*; *N. curculionis* in larvae from *H. annuus*, *H. nuttallii* Torrey and Gray, and *H. maximiliani*; *N. rufus* (Riley) in larvae from *H. annuus* and *H. petiolaris*; and *U. femoratus* in larvae from *H. annuus*, *H. petiolaris*, *H. nuttallii*, and *H. maximiliani*. A pteromalid wasp, *Eutrichosoma mirabile* Ashmead, was reared from larvae collected in heads of *H. annuus* and *H. maximiliani*. Three adults identified only as *Nealiolus* sp. also were reared from *H. maximiliani* collected in Montana. These parasitoids were probably *N. curculionis*, but the specimens could not be positively identified to species. The braconid *U. femoratus* was the most prevalent species of parasitoid collected, representing about 45% of the adults reared from seed weevil larvae. Because many collections contained both species of seed weevils, it was difficult to determine which was the host of each parasitoid species. However, *E. mirabile*, *N. curculionis*, and *Nealiolus* sp. probably were attacking *S. sordidus*, since they were reared from heads in which only gray sunflower seed weevil adults emerged (Charlet and Seiler 1994).

Information on parasitoids associated with the **banded sunflower moth** is limited. Westdal (1975) reported that in Manitoba, Canada, at least two species of parasitoids including *Chelonus phaloniae* Mason (Braconidae) and *Glypta* sp. (Ichneumonidae) attack banded sunflower moth larvae and are able to maintain the pest below economic levels. An additional species of *Chelonus*, *C. shoshoneanorum* Viereck, was mentioned as a larval parasitoid of the banded sunflower moth in Canada by Rogers (1980). However, it was not included in the extensive list of parasitoids of head-infesting insects of cultivated and native sunflower from Canada by Sharkey et al. (1987). Two additional braconid parasitoids reared from banded sunflower moth larvae in Canada include *Bassus arthurellus* Sharkey and *Bracon mellitor* (Say) (Sharkey 1985, Sharkey et al. 1987). Studies in North Dakota and Minnesota on cultivated sunflower showed that the banded sunflower moth is parasitized by the braconids *C. phaloniae* and *M. ancylivorus* and the ichneumonid wasps *Glypta prognatha* Dasch, *Glypta* sp., *Mastrus* sp., and *Trathala* sp. (Charlet 1988, Bergmann and Oseto 1990). Krombein et al. (1979) also list *M. ancylivorus* as a parasitoid of the banded sunflower moth. The most abundant parasitoids of the banded sunflower moth in cultivated sunflower fields in North Dakota, South Dakota and Minnesota are *C. phaloniae* and *G. prognatha*, and the relative impact of each parasitoid species on *C. hospes* appears to vary from year to year, with a total of 40-70% of overwintering larvae parasitized (Charlet 1988, Bergmann and Oseto 1990).

The **sunflower moth** larva is attacked by numerous parasitoid species of both Hymenoptera and Diptera. The earliest survey for parasitoids of the sunflower moth was conducted during 1933 in Illinois, Missouri, and Louisiana, in an attempt to provide more effective natural enemies for the moth in Cuba (Satterthwait and Swain 1946). The tachinid, *Nemorilla pyste*

(Walker) and the braconid, *Dolichogenidea homoeosomae* Muesebeck, were present in Cuba, but the level of control was inadequate. The hosts surveyed for sunflower moth larvae included two native sunflowers, *H. annuus* and *H. tuberosus* and other species of Asteraceae. Satterthwait and Swain (1946) and Satterthwait (1948) recovered a total of 12 species of parasitoids, including six Braconidae (*Bracon mellitor*, *B. nuperus* Cresson, *Chelonus altitudinus* Viereck, *Dolichogenidea homoeosomae*, *Bassus buttricki* (Viereck), and *Macrocentrus ancylivorus* Rohwer), two Ichneumonidae (*Cremastus epagoges* Cushman and *Diadegma openangorum* (Viereck)), and four Tachinidae (*Clausicella floridensis* (Townsend), *Erynnia tortricis* (Coquillett), *Leskiomima tenera* (Wiedemann), and *Lixophaga variabilis* Coquillett). Attempts to establish parasitoids in Cuba failed because only males of *D. openangorum* were successfully reared (Satterthwait and Swain 1946).

Teetes and Randolph (1969) reared 11 species of parasitoids from sunflower moth larvae in Texas collected on three hosts, *Gaillardia pulchella* Fougerous, native *H. annuus* and cultivated sunflower. New records included two braconids, *Apanteles epinotiae* Viereck and an undetermined *Agathis* sp., three ichneumonids, *Cremastus* sp. and two undetermined species of *Pristomerus*, and one tachinid, *Clausicella neomexicana* (Townsend). *Clausicella neomexicana* was the most prominent species of parasitoid recovered from larvae collected on cultivated and native sunflowers. They noted that the parasitoid fauna was more diverse on native sunflower than on cultivated sunflower. Larvae were not killed by any of the parasitoids until a late instar, after the sunflower heads had sustained considerable feeding damage (Teetes and Randolph 1969). Some additional sunflower moth parasitoids recovered in Texas by Rogers (1980) included *Habrobracon gelechiae* (Ashmead) (Braconidae), *Mesostenus gracilis* Cresson (Ichneumonidae), *Pteromalus* sp. (Pteromalidae), and three tachinids (*Clausicella opaca* (Coquillett), *Hyalomya* sp., and *N. pyste*).

In the early 1980s, Beregovoy (1985) made collections of sunflower moth larvae from native *H. annuus* and two other Asteraceae (*Gaillardia pulchella* and *Coreopsis tinctoria* Nuttall) in the Great Plains from Arizona and Texas to North Dakota to determine their parasitoid fauna. He recovered 16 species of primary parasitoids in five families, of which five had not previously been reported from the sunflower moth (*Pristomerus austrinus* Townes and Townes (Ichneumonidae), *Elasmus setioscutellatus* (Crawford) (Eulophidae), *Goniozus floridanus* (Ashmead) (Bethylidae), *Blondeliini* sp., and *Pseudachaeta* sp. (Tachinidae)). *Clausicella opaca* was the most common tachinid recovered by Beregovoy (1985). This species also was reported from the sunflower moth in Texas (Reinhard 1946) and Mexico (Tejada and Blanc 1976). The most abundant Hymenoptera collected by Beregovoy (1985) were *M. ancylivorus*, *D. homoeosomae*, and *C. altitudinus*.

Parasitoid records for sunflower moth in the northern Great Plains are more extensive for Canada than for the United States. Populations of the sunflower moth in Manitoba were reported by Westdal (1975) to be held in check by natural enemies which included the parasitoids, *B. buttricki*, *M. ancylivorus*, and *D. openangorum*. A survey of sunflower moth parasitoids from both native and cultivated sunflower in Saskatchewan and Alberta reported 10 species of Hymenoptera (Arthur and Campbell 1979). Total parasitism was higher in native sunflowers than in cultivated sunflower, which the authors speculated was due to a higher

exposure of hosts in the smaller blooms of native sunflowers than in the larger cultivated heads. However, they noted that some species (e.g. *M. ancylivorus* and *Agathis* spp.) have longer ovipositors and have rates of parasitization that are equal to or slightly higher on cultivated sunflower than on native sunflowers. Two undetermined species of *Agathis*, two new species of *Cremastus*, and the ichneumonids, *Scambus canadensis* Walley and *S. tecumseh* Viereck were new records of sunflower moth parasitoids reported by Arthur and Campbell (1979). Sharkey et al. (1987) recently expanded the list of Hymenoptera attacking the sunflower moth in mid-western Canada with the addition of *Bassus nigripes* (Cresson) (Braconidae), *Parania geniculata* (Holmgren), *P. pulchra* Dasch, and *Trichomma maceratum* (Cresson) (Ichneumonidae). Although records from Canada do not include any parasitic Diptera, Schulz (1978) noted that two tachinids have been reared from sunflower moth larvae collected in North Dakota. *Erynnia tortricis* was previously recorded from the sunflower moth, but *Lixophaga plumbea* Aldrich was a new record. Two other species of parasitoids have been reported to attack larvae of the sunflower moth, *Pristomerus pacificus* (Cresson) (Ichneumonidae) (Schulz 1978) and *Spilochalcis flavopicta* (Cresson) (Chalcididae) (Krombein et al. 1979).

Parasitoids have been reported to attack three stages of the **sunflower beetle**. Eggs are parasitized by the pteromalid, *Erixestus winnemana* Crawford in North Dakota, Minnesota, and Manitoba, Canada, but the reported parasitization rates are much lower in the U.S. than in Canada (Neill 1982, Charlet 1992). Larvae are attacked by two species of tachinids, *Myiopharus macellus* (Rheinhard) (=*Doryphorophaga macella*) and *M. doryphorae* (Riley) (=*Doryphorophaga doryphorae*) in Manitoba, Canada, and North Dakota and Minnesota. *Myiopharus doryphorae* has only been recovered from Canada and is extremely rare, constituting <1% of parasitoids reared from sunflower beetle larvae. The life history of *M. macellus* is well synchronized with the life history of its host, and the rate of parasitization is high in both Canada and the U.S. (up to 70 and 100%, respectively). Adult sunflower beetles are parasitized by the tachinid, *Myiopharus* sp. Approximately 0.2 to 17% of adults in Manitoba are attacked, but less than 2% of adults are parasitized in North Dakota and Minnesota (Neill 1982, Charlet 1992).

There has been a limited search effort for parasitoids of the sunflower beetle in native sunflowers. In 1995, over 250 sunflower beetle larvae were collected from six species of *Helianthus* at 15 locations in North Dakota. The species included, *H. annuus*, *H. petiolaris*, *H. nuttallii*, *H. tuberosus*, *H. maximiliani*, and *H. pauciflorus* Nuttall ssp. *subrhomboideus* (Rydberg) Spring and Schilling. Sunflower beetle larvae from four of the species were parasitized. Parasitoids were not recovered from *H. maximiliani* and *H. pauciflorus*, probably because of the low numbers of larvae collected. All parasitoids were *M. macellus* (unpublished data). Because research on the parasitoids of the sunflower beetle in cultivated as well as native sunflower has received little attention, it is possible that further research in different locations will produce additional natural enemies not yet encountered.

Conclusions

Challenges for the future in biological control include additional studies on the complex of

predators and parasitoids in cultivated sunflower. Investigations also need to be conducted on the biology and population dynamics of the natural enemies associated with the major pest species and the interaction of the different IPM practices to ensure their compatibility with the natural enemies. We need to evaluate the impact of the predators and parasitoids and ways to improve their control through conservation and augmentation. Searches for new enemies in native sunflowers in areas of origin, centers of distribution, and climatically compatible locations should also be implemented. An additional area to consider is the importation of natural enemies from related hosts. A search for more effective parasitoids of the sunflower moth could include the importation of natural enemies of the European sunflower moth, *Homoeosoma nebulellum* Denis and Schiffermüller, which is attacked by a complex of parasitoids in western and eastern Europe (Sakharov 1925,Horvath and Bujaki, 1992, Reymonet et al. 1993).

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Biological Control: Insect Pathogens

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Introduction

Human awareness of insect diseases probably began with the honey bee and the silkworm. The fungi were the first pathogens to be associated with insects probably because they are visible to the naked eye. The first experimental demonstration of an insect pathogen was made by Agostino Bassi in the early 19th century and the pathogen, *Beauveria bassiana*, bears his name (Tanada and Kaya 1993). Reports of diseases from infections with much smaller bacteria and viruses began in the early 20th century. The first description of *Bacillus thuringiensis* (Bt) in 1902 was credited to Ishiwata (Bulla et al. 1980), but then largely forgotten. Its possible use in insect control resurfaced with a publication by Steinhaus (1951). Successes with the use of microbial insect control came largely after 1950 when the biology and ecology of the microbial pathogens became better understood. At present, there are about 1500 known microorganisms or byproducts that have been identifed as potentially useful insecticidal agents (Miller et al. 1983). About 100 bacteria have been reported as entomopathogens and the most famous of these is Bt. More than 500 species of fungi infect insects (Miller et al. 1983). Many viruses are pathogenic to insects and of these the baculoviridae are promising because they are highly pathogenic, infect insects almost exclusively, can be genetically engineered and some have been commercially developed (Crook and Jarrett 1991). Microbial control of sunflower insect pests has not been significantly explored and is an area in need of study. This paper is concerned with some initial efforts to study microbial pathogens of the banded sunflower moth (*Cochylis hospes* Walsingham) and the sunflower stem weevil (*Cylindrocopturus adspersus* LeConte).

Materials and Methods

Insects and holding conditions.

Cochylis hospes and *C. adspersus* are routinely reared in the laboratory on insect diet and the larval, pupal or adult stages of these insects are available as needed for bioassays of insecticidal proteins or insect pathogens. Insects were reared in environmental chambers maintained at 28 ± 1 °C, 50% relative humidity, and a 15:9 L:D cycle.

Bt tests. Bt toxin was prepared by the method of Venkateswerelu and Stotzky (1990). Test diets were prepared with 10.0, 2.0, 1.0, 0.4, 0.2, 0.15, or 0.1 ug/ml of Bt toxin by blending 5.0, 1.0, 0.5, 0.2, 0.1, 0.75, or 0.05 mg of Bt toxin for 1 min. into 500 ml of rearing diet that had been cooled to 50°C. The insect diet was cut into 2 by 1 cm^2 pieces. For each test, a piece of diet from a diet prepared with one of the above toxin concentrations was added to each of 50 vented 1 ml microfuge tubes, and a piece of control diet to each of 50 control microfuge tubes. Larvae were placed individually in each of the tubes and held in an environmental chamber at 28 ± 1 °C,

50% relative humidity and a L:D cycle of 15:9 hours. Insects were observed daily for mortality and changes in development.

The pathogenicity of *Metarhizium anisopliae* (American Type Culture Collection ATCC # 22099) and *Beauveria bassiana (*Naturalis® Troy Biosciences, Phoenix, AZ) was examined by infecting 5^{th} instars of the banded sunflower moth and sunflower stem weevil and holding the infected larvae for 3 weeks in two environmental chambers maintained at 60 – 70% relative humidity, and a 15:9 L:D cycle. One of the chambers was maintained at 20 ± 1 °C and the other was held at 25 ± 1°C. Thirty 5^{th} instar banded sunflower moth larvae were counted into each of 6 petri dishes and 30 sunflower stem weevil larvae into each of 5 petri dishes. Banded sunflower moth and sunflower stem weevil larvae were infected by transferring them, 30 at a time, to a tube containing 10^6, 10^5, 10^4, 10^3, 10^2, or 0, and 10^8, 10^7, 10^6, 10^5, or 0 conidia / ml, respectively. Each experiment was replicated 5 times. Conida were counted with a hemocytometer. Fifth instars, which have ceased feeding, were used for tests of *M. anisopliae* and *B. bassiana* to prevent complications that would arise from diet spoilage in the presence fungi. Cessation of feeding by 5^{th} instar banded sunflower moth larvae is marked by a change in color about 2 days after it has molted to the fifth instar. Stem weevil larvae become fifth instars 4 weeks after the eggs are placed on diet. Treated Banded sunflower moth larvae were confined individually to 1 ml vented microfuge tubes with a piece of moist potting foam to pupate in. Ongoing experiments concerned with the rearing and development of the banded sunflower moth have suggested that venting of the tubes and material to pupate in facilitated development and pupation. Treated sunflower stem weevil larvae were confined to the wells of Falcon tissue culture trays and placed in the environmental chambers without further adjustment in holding conditions.

LC_{50}s were determined with LeOra software which performs the computations for probit analysis. It is based on probit analysis developed by Finney (1971).

Results and Discussion

The effect of Bt on the mortality and development of the banded sunflower moth.

The effect of Bt toxin on mortality and development of banded sunflower moth larvae depended on the dosage and the instar. Inhibition or cessation of feeding appeared to occur almost immediately after exposure to Bt diet based on a lack of fecal pellets, prolonged develoment time, and fatbody depletion (Barker, 1998). It was found that the LC_{50} differed with the instar, with 5^{th} instars requiring about 0.5 ug Bt toxin/ ml of diet (Table 1).

Recovery from exposure to Bt toxin.

Banded sunflower moths did not seem to be permanently damaged by ingestion of diet with a lethal concentration of 1 μg of toxin / ml of diet. Fifty to over 90% of the larvae that were removed from Bt diet to a control diet resumed feeding and development (Barker, 1998).

Table 1. Bt toxin dosages for 50 % mortality of *C. hospes* larvae

Instar	Avg. wt (mg) control instars	LD_{50} µg/ml
1st	0.009 ± 0.0004	---
2nd	0.23 ± 0.03	0.137 ± 0.007
3rd	0.74 ± 0.09	0.152 ± 0.016
4th	5.45 ± 0.17	0.248 ± 0.004
5th	9.5 ± 0.40	0.498 ± 0.018

Intact *Bacillus thuringiensis*

Infection of 5th instars of the banded sunflower moth with intact *B. thuringiensis* was characterized by inactivity, disintegration and blackening of the tissues, and death about 24 – 48 hours after exposure to the pathogen. The intact organism has other toxins in addition to the protoxin and secondary effects such as septicemia that are not induced by the protoxin alone (Bulla et al. 1980).

Mortality of the banded sunflower moth and sunflower stem weevil infected with *M. anisopliae* and *B. bassiana*

Infection of banded sunflower moth larvae with *M. anisopliae* and *B. bassiana* was characterized by the appearance of black spots on the cuticular surface. Both of these fungi have chitinolytic activity (Tanada and Kaya 1993) and black lesions appear where penetration of the insect cuticle has occurred. Brownish spots sometimes appeared on the cuticular surface of the sunflower stem weevil but usually a thin coating of white mycelia appeared which became more dense as the infection progressed and the carcass turned brown, reddish or black. Larvae infected with *M. anisopliae* turn greenish as conidia develop.

Fifth instars of the banded sunflower moth appeared to have similar suceptibility to infection with conidia from *M. anisopliae* than *B. bassiana* based on the number of conida that caused 50% mortality (Table 2). The banded sunflower moth was more suceptible to these fungal pathogens

than was the sunflower stem weevil. The LC_{50} for these pathogens with respect to the sunflower stem weevil was 2.5 to 3.5 million conidia / ml at 25 °C.

Table 2. Infection of 5th instar banded sunflower moth and 5th instar sunflower stem weevil larvae with conidia of *M. anisopliae* and *B. bassiana*.

Treatment	Insect	Temp.	LD_{50} Conidia / ml
M. anisopliae	Banded sunflower moth	20°C	13,303.0
M. anisopliae	Banded sunflower moth	25°C	6,635.0
B. bassiana	Banded sunflower moth	20°C	13,974.0
B. bassiana	Banded sunflower moth	25°C	6060.0
M. anisopliae	Sunflower stem weevil	20°C	305,780.0
M. anisopliae	Sunflower stem weevil	25°C	2,877,484.0
B. bassiana	Sunflower stem weevil	20°C	---*
B. bassiana	Sunflower stem weevil	25°C	3,458,686.0

*data under completion

Future directions

A large body of insect pathogens or their by products exist that can be exploited for insect control. Virtually all pest species are subject to some level of natural biological control imposed by pathogenic and antagonistic effects of microorganisms already present in the environment. We will be surveying for pathogenic microorganisms that contaminate larvae of the stem weevil, banded sunflower moth and the red seed weevil, *Smicronyx fulvus* LeConte . The biology, ecology and pathogenicity of new agents with respect to sunflower insects will be an important objective. The identification of microorganisms, particularly viruses and bacteria is a major obstacle in the study of sunflower insect pathogens. We have acess to a computerized Biolog system for identification of bacteria, and we are developing expertise in DNA (RNA) fingerprinting of microorganisms. Samples can be sent to ATCC (American Type Culture Collection) along with any information we can provide and get the organism identified, but that will be expensive so we will do as much as we can ourselves.

Concurrently, we will be examining the pathogenicity to the sunflower stem weevil and banded sunflower moth of EPA approved pathogens such as *Bacillus popilliae, Bacillus lentimorbus, Bacillus thuringiensis, Beauveria bassiana, Metarhizium anisopliae,* and *Autographica californica.* Pathogens that already have EPA approval should be a good starting point to extend microbial control to sunflower insects because their biology and ecology have already received attention and many of the additional problems that are of major concern with their development as microbial insecticides such as their effect on ecosystems and non-target organisms, costs, environmental persistence, speed of action, and production will also have received some attention.

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Genetic Engineering for Control of Sunflower Pests

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Introduction

In spite of the many advances in pest management over the last 50 years, pest insects are still estimated to cause annual losses of 10-15% in the production of agricultural crops. It has been suggested that many of the advances chemical, biological and cultural forms of pest control have been offset by increased plantings of more susceptible crop varieties (Metcalf, 1996). The optimism associated with genetic engineering is, in part, due to the enthusiasm associated with having pest resistant crop varieties to use in concert with other forms of pest management.

Insect Pests of Sunflower

Pest resistance will likely be the first trait genetically engineered into sunflowers. The basis for this pest resistance will undoubtedly be due to B.t. toxins and genes. To expedite the development of B.t. in sunflowers and other crops, Mycogen Corporation and Pioneer HiBred have joined in a research alliance. This alliance was formed to identify B.t. toxins and develop insect resistant corn, sunflower, canola, soybeans, wheat and sorghum. The insects targeted in the North American sunflower program are listed in table 1. Although not currently considered a target, we are aware of the damage that the sunflower midge is causing and may consider it a target in the future.

Table 1. Insect Pests of Sunflower

Common Name	Scientific Name
Sunflower Moth	*Homoeosoma electellum*
Banded Sunflower Moth	*Cochylis hospes*
Sunflower Stem Weevil	*Cylindrocopturus adspersus*
Red sunflower weevil	*Smicronyx fulvus*
Sunflower Beetle	*Zygogramma exclamationis*

B.t. as a source of insect active proteins

B.t. or *Bacillus thuringiensis* is an entomopathogenic bacteria. The pathogenicity of B.t. strains to lepidoptera and diptera (principally mosquitoes) has long been known. The basis for the activity against lepidoptera and diptera is a protein inclusion or crystal that is

produced during the sporulation phase of growth. This inclusion contains one or more individual proteins, called delta-endotoxins, that are insecticidal.

B.t. researchers have long noted diverse crystal morphologies and that the individual proteins making up the crystals vary markedly in molecular weight. Another significant observation was that many B.t. strains lacked toxicity or pathogenicity to lepidoptera or diptera. In the early 1980's Mycogen Corporation adopted a working hypothesis that the "inactive" B.t. strains may, in fact, represent strains that are active against invertebrates other than lepidoptera and mosquitos. To test this hypothesis and to explore the full commercial utility of B.t., we began a testing program to investigate the spectrum of activity of B.t. This investigation revealed strains active against a variety of invertebrates such as hymenoptera, additional diptera such as the common house fly, several families of beetles, mites, plant and animal parasitic nematodes, mollusks such as the zebra mussel, trematodes and protozoa (Feitelson, et al., 1992). Based on these results, it has been suggested that B.t. strains can be discovered for virtually any pest target as long as an appropriate assay can be developed to monitor ingestion activity.

At the same time the host range of B.t. strains has been expanded, researchers from a variety of institutions have identified numerous new protein delta-endotoxins from B.t. (Schnepf et al., 1998). Figure 1 illustrates the rather remarkable structural diversity that exists for delta-endotoxins. In addition to the host range, another opportunity

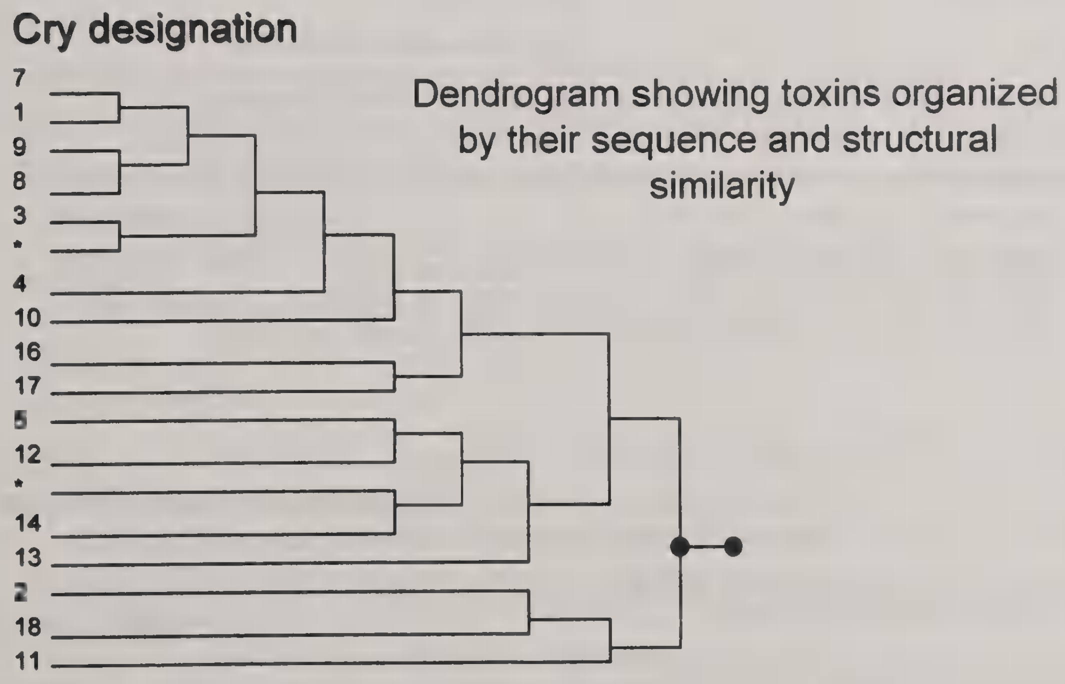

Figure 1. Dendrogram showing toxins organized by their sequence and structural similarity (after Schnepf et. al, 1998)

afforded by structural diversity is the potential for resistance management. Research on the binding of B.t. toxins to molecular targets in the midgut have revealed the existence

of multiple receptors (Schnepf, et al., 1998). The existence of multiple receptors suggests the possibility that insect resistance to B.t. may be toxin specific. Studies conducted against various insects indicate that this can be the case for some toxins. For example, colonies of diamondback moth and Indian meal moth have been selected for resistance to Cry1Ab but not to Cry1C (Tabashnik, 1994).

Opportunities for disease resistance in sunflower

A number of fungal diseases impact sunflower yields (Berglund, 1994). Some of the more important diseases in North America are listed in table 1. The development of disease resistance is an important opportunity for genetic engineering. Last winter,

Common name	Scientific name
Sclerotinia wilt, head rot, middle stalk rot	*Sclerotinia sclerotiorium*
Rust	*Puccinia helianthi*
Downy mildew	*Plasmopara halstedii*
Phoma black stem	*Verticillium dahliae*
Phomopsis stem canker	*Phomopsis helianthi*
Rhizopus head rot	*Rhizopus sp.*
Charcoal rot	*Macrophomina phaseolina*

Mycogen announced a licensing agreement with Demeter Biotechnologies, Ltd. to develop transgenic disease-resistant varieties. The basis of this technology is the development of synthetic derivatives of antimicrobial peptides (AMP) isolated from naturally occurring organisms. The AMP's, known as magainins, mellitins, defensins, and cecropins, are produced by many organisms as a line of defense against microbial attack. Unlike the native peptides, the synthetic analogs developed by Demeter have shown antimicrobial activity when expressed in tobacco, peanut and potato.

Issues associated with the use of engineered crops

The structural diversity and expanding host range for B.t. suggests that we should be able to engineer sunflower to resist damage from most if not all insect pests. Likewise, the demonstration of disease resistance through the expression of synthetic AMP's indicates that the potential to manage diseases of sunflower. The wise use of this new technology will need to be the focus of sunflower researchers. A recent book has focused on risks associated with new technology (Tenner, 1996). In this book, the author introduces the concept of "revenge effects" associated with new technology. Revenge effects are defined as unintended consequences of ingenuity. While the author describes a number of examples of technological developments that have gone awry, the book is not pessimistic. Rather, an argument is made that technological optimism means in practice, the ability to recognize bad surprises early enough to do something about them. A

question to ask ourselves is whether our understanding of wild and domestic sunflower as well as microbial and insect pests is adequate to anticipate the unintended consequences of genetic engineering in sunflowers.

We can look for "revenge effects" in sunflower both within and external to the agricultural environment. Within the agricultural environment, the selection of pest that develop resistance to transgenic control mechanisms represents a threat the longevity of this technology. External to the agricultural environment, the out-crossing of an engineering gene into the environment represents a potential revenge effect. The impact of out-crossing are particularly important for sunflower since the crop is native to North America. Issues associated with outcrossing have been defined for other crops (Schmitt and Linder, 1994). Many of the same issues apply to sunflower.

Summary

With developments in the discovery of new pest control genes, sunflower plants exhibiting multiple types of pest resistance are in the near future. Now is a good time to begin evaluating the benefits in terms of decreased chemical inputs. The benefits of genetic engineering will be greatest if we take time to analyze and avoid the unintended consequences of this new technology.

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Host-Plant Resistance Against Sunflower Insects:

Role in Integrated Pest Management and Present Status of Resistant Lines.

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I. The Goal of Plant Resistance and How it is Selected

a. Relationship of resistant sunflower to IPM.

The development of insect resistant lines for control of insect pests of sunflower, while a goal which stands by itself in importance, should not be considered as the principal solution to all insect problems of sunflower. Above all, resistance should be considered primarily in the larger context of a comprehensive insect pest management program. Within this context, resistant plants have a threefold role (Dent 1991). First, resistant plants may provide the stable base on which to build other strategies. Lower starting levels of pest populations are easier to control than are larger outbreaks. If resistant plants support fewer insects, then biological control strategies can be established that have higher chances of success. Second, the resistant plants by themselves may keep the pest population below economic threshold levels, so that additional strategies of control need not be implemented. Third, resistant plants may reduce the need for chemical pesticides. As a result of this reduction, resistant plants may help reduce interference between other strategies of the pest management program.

Many of the fundamental goals of insect pest management can be accomplished if resistant plants are incorporated into the framework of an integrated plan (Wintersteen and Higley 1993). First, resistant plants are often an economically advantageous approach. Usually the cost of resistant seed stock is no more than that of susceptible stock, unless there may be a biotechnology fee for transgenic seeds. Second, resistant plants may prevent an accumulation of insects resistant to other strategies. The resistance in plants may be a morphological, or may be controlled by multiple genes, both of which decrease the likelihood that resistance may be overcome. Thus, resistant plants may be able to make the existing IPM plan more durable. Third, resistant plants are ecologically useful in that they avoid the need for applying toxic chemicals to the environment. If the plant resistance is characterized by expression of novel chemicals, or chemicals that are formed in high concentration, then these will be expressed within the plant, and are not excreted to become an environmental issue.

Despite these useful properties, it cannot be assumed that plants resistant to insects require no special conditions or allowances; resistant plants may interact either positively or negatively with other parts of the pest management program. Resistant plants should not be added to an existing management scheme without further field studies. The role of natural enemies, cultural inputs, and chemical controls may be quite different with the substituted resistant host plants. For

example, if the main pest species is reduced from a constant pest to a sporadic one, then new monitoring strategies, new thresholds and new strategies to contain these pest outbreaks may be needed (Kennedy et al. 1987).

b. What types of resistance to insects can be selected?

The type of resistance that may be developed is an important consideration for its usefulness. That is, a mechanism of tolerance may be useful in some crop plants, but if the pest load in a tolerant line did not lead to yield loss but did allow seed quality to be degraded, then it is not useful resistance. The first type of resistance is antixenosis. This is nonpreference by the insect for the host, but this term is not used for the resistance type, since it refers to the insect, not the plant, as do the other resistance types. Any property of the plant that leads to reduced colonization, or to increased emigration is termed an antixenotic mechanism. These mechanisms may be both morphological and biochemical. The second type of resistance is antibiosis, in which a plant property interferes with growth, development or reproduction of the insects. Poor growth, or restlessness of the pest may allow beneficial insects or pathogens to have some additional impact on the pest. The third type of resistance is tolerance, in which the load of a pest which might debilitate or cause yield loss on a standard plant have no effect on the tolerant host plant. Other types of resistance have been included under the title "pseudo resistance" but this term is perhaps a poor one. This last category includes resistance based on time or spatial parameters. In this category is resistance in which plant developmental events might avoid the pest's typical time of appearance. For example, in a plant susceptible to a flower-infesting insect species, flowering might occur at an earlier or later time than when the pest is usually present. Finally, one should also include the category of resistance that is initiated by biotic or environmental stress, that is, induced resistance. The precise mechanism of expression of these induced responses may be the same as one of the first three types of resistance.

c. Breeding durable resistance.

As we investigate the basics of resistance, we might also ask whether there is more than one strategy for developing resistance. The classical view of resistance selection is that researchers will attempt to identify specific mechanisms by which plants will resist specific pests. The genes for these resistance mechanisms are incorporated into the appropriate high yielding cultivars. This has been termed vertical resistance, because there is a specific gene that corresponds to a specific pest, or to a biotype of a pest (Robinson 1976; Dent 1991). This type of resistance may be short-lived because biotypes of the pest may evolve to circumvent whatever resistance was found. A broader type of resistance, horizontal resistance, is that which encompasses many mechanisms of resistance. If multiple genes are involved with this resistance, multiple pests may be controlled. This strategy also limits the probability that biotype resistance by a single pest may occur. Some entomologists (e.g., de Ponti 1983) have confused the original terminology of Robinson (1976) and have defined horizontal resistance as the most common, type, which is a partial one controlled by many genes. However, using the conclusions of Dent (1991) and the original meaning of the term, horizontal resistance is that which is obtained when selection is made exclusively for resistance to one insect pest. Furthermore, unless special effort is made to include multiple resistance genes in the development of a cultivar, they may be lost in a mass selection scheme.

Virtually all of the effort in producing sunflower cultivars that are insect-resistant is directed towards finding vertical resistance (in the original sense of the term).

d. Sources of sunflower resistance.

To understand the current attempts at developing resistant lines of sunflower, we should keep in mind the sources from which resistance is being sought. *Helianthus annuus* is an annual species common in North America, and the cultivated sunflower is derived from these. Often the first approach for a breeding program is to seek resistance among plants collected in the point of origin of the original source of the cultivar. Some of the germplasm from the source should have useful genes for resistance to insect pests. A large collection of *H. annuus* germplasm is readily available from the USDA-ARS Plant Introduction Station at Ames, Iowa. The drawbacks of this source are that it may take a lengthy period to get the resistance genes transferred into agronomically useful cultivars.

Another source of resistance genes are the sunflower inbred lines maintained by Federal and State sunflower breeders, since inadvertent selection for useful characters is always possible. Also, while inbreds should be genetically uniform, "off-types" and spontaneous mutations cannot be excluded as sources of useful properties. The frequently high resistance of non-*annuus* annual and perennial species to typical sunflower pests make these also an important resource for resistance. The largest drawback is the difficulty of assuring that the resistance will transfer into the *H. annuus* species, since the perennial species and their genetic structure may be quite unlike that of *H. annuus*.

e. Beyond classical selection, can technology help produce resistant sunflower?

Additional contemporary strategies for developing resistant plants can be cited. Mutagenesis has not been commonly used as a source of insect resistance, but there is no reason to presume that it is not a practical strategy. The principal drawback for mutant selection is that about a thousand plants or even more may be needed to find changes in any given character. Another strategy, plant transformation, has been used with increasing frequency by seed-producing agricultural companies (see review in this issue). Foreign genes can be transformed into sunflower from any source. The concern in the use of this strategy is that single, novel genes may not be durable over a long period of time. If a *Bacillus thuringiensis* gene is used, resistance may easily develop because of its presence in a variety of agricultural crops. Exposure of certain oligophagous insects to these gene products in a number of transformed crops will hasten the onset of such resistance. Insects that are not now major pests of sunflower always have the potential to become pests of the sunflower. Although our current major and minor pest species are specific to sunflower, some other insects are known to successfully feed on sunflower and could potentially become common pests, such as *Heliothis virescens* and corn rootworms (Roseland, personal observations). If these other insects have been exposed to selection in other crops as well in *B.t.*-transformed sunflower, they will be pre-adapted to become pests in sunflower, too.

Finally, biological techniques may be useful in specially selecting resistant characters. If a character has been shown to correlate with resistance, this character may be more easily selected

than is actual resistance to the pest. In the early 1980s, plant pathologist R.R. Urs suggested that the cupping damage in sunflower by the sunflower midge might be caused by auxin induced by insect feeding. He proposed that one might select midge-tolerant sunflower by resistance to injection of an auxin analog, such as 2-4-D into developing sunflower heads. Selection for resistance to cupping would produce tolerant plants, since such plants would respond weakly to the midge-induced hormone imbalance (Brewer et al. 1994).

Some morphological traits have been shown to confer resistance, and may be selected directly to improve the resistance of plant cultivars. Thus, one could examine resistant plants for excretions, hairs, or trichomes. For example, the glandular trichomes of *H. maximiliani* have high concentrations of sesquiterpene lactones that are located in the glandular trichomes on parts of the floret. These trichomes are the source of deterrence to feeding of the sunflower moth, *Homoeosoma electellum* Hulst (Gershenzon et al. 1985).

Characters for resistance which are known to be chemically based, and which can be analyzed by a chemical procedure, can also be selected in populations. When either the presence of a resistance causing chemical or its concentration can be assayed, a powerful means is available to assess its biological activity long before a bioassay is accomplished. For example, the coumarins are known to be deterrents to feeding of the sunflower beetle, *Zygogramma exlamationis* (Olson and Roseland 1991). These can be quantified by HPLC and cycles of selection of lines for high coumarin content can then be done. Selected lines high in coumarins can ultimately be verified using bioassay for resistance to sunflower beetle.

II. Progress in Breeding Resistant Sunflower

a. Breeding for sunflower midge resistance

Various attempts have been made to find sunflower midge *(Contarinia schulzii* Gagne) resistant or even midge tolerant lines of sunflower. Lines selected during the period 1980-1985 were reported in Miller (1986). It has been shown that some hybrids already have some resistance (Anderson and Brewer 1991, Brewer et al. 1994, Brewer and Charlet 1997). Observations of *annuus* accessions (Table 1 [Gao 1996]) also indicate that some resistance can be found in these as well. Among resistant hybrids, the types of resistance were thought to include all classes, but resistance to infestation seemed to be the most common type of resistance (Table 2. [Anderson and Brewer, 1991]). Tables of midge resistance in hybrids that are presently grown have been published (Brewer and Charlet 1997), and the best lines show resistance that is about 60% of the damage ratings of susceptible check lines.

Table 1. Mean damage ratings from sunflower midge infestation. (After Gao 1996)

PI No.	Damage Rating*	N
HA 894 (susceptible)	2.44a**	41
431506	1.21b	42
170424	0.37c	27
170411	0.08c	34

*Scale: 0=no damage 5=complete damage, no seeds

** Significance determined by t-test. Means within columns followed by the same letters are not significantly different (P<0.05)

Table 2. Components of resistance to sunflower midge (After Fig. 3, Anderson and Brewer 1991).

	Line evaluated (% ascribed to specified resistance)			
Type of resistance	IS 394	84-108	83-202	DO643-7E
Resistance to Infestation	14.5	26	25.5	16.4
Antibiosis	16.4	8	18.2	0
Tolerance	7.3	17.1	11.1	39.1

A technique for selecting lines with tolerance to sunflower midge has been recently developed. Damage by sunflower midge larvae to the developing sunflower can be mimicked by chemical treatment, and a procedure has been worked out in detail (Brewer et al. 1994). Sunflower heads were injected with 2-4-D which induced distortions of the mature head similar to the midge-induced damage that leads to seed loss. Lines that are tolerant of sunflower midge infestation also should not have a significant cupping response to this injected auxin. The induced damage caused by a three-point injection of auxin mimic in 4.5-5cm diameter heads correlated well with the damage induced by the same lines grown in the field, but naturally infested (Brewer et al 1994). This technique is presently being used to help identify resistant lines, as will be discussed next.

Miller (unpublished) has used the sunflower "midge tolerant component" (MTC) line and some of those contributed by Brewer (unpublished) and crossed them with USDA 821 and various semi-dwarf lines. The F_2 generation progeny were planted and injections made with 2-4-D to detect those plants most likely to be similarly tolerant to sunflower midge damage. Selection of auxin resistant lines was continued for two additional generations, with a total of 1000 plants having been injected. In 1997, severe midge pressure on the developing germplasm was encountered (Miller, unpublished) so that the least damage incurred was 3.5 on a 5 point scale (0= no damage, 5=maximum damage). Efforts are continuing to select resistance to midge in this population.

b. Progress on seed weevil resistance

Brewer, Charlet and others have sought seed weevil (*Smicronyx fulvus* LeConte) resistance in cultivated-type accessions of sunflower available at the USDA Plant Introduction Station, Ames, IA. Typically, some lines can be found which when compared to a standard check, show many fewer damaged seeds by visual inspection (Gao 1996). When these lines are assessed for total insect feeding, including unemerged larvae that are revealed by x-rays of the seeds, these same lines may not be so resistant (Table 3, [Brewer 1994; Brewer and Charlet 1995]). Another difficulty in evaluating the amount of resistance in various lines is the variability of flowering time, either being earlier or later than the check lines. Consequently, weevils may not be available to oviposit on lines at the same time as comparison lines. Further, there exists within the same accession different morphologies of seed type and floret color, that may be associated with either resistance (e.g. PI 174024: white seeds) or susceptibility (PI 174024: black seeds; Gao 1996). This suggests the need for evaluating a subselection of accessions so that inbred lines are evaluated rather than the diverse assemblage of genes that might be found within a typical accession. While there is some evidence for "low levels" of larval antibiosis and also of some adult non-preference in various tested accessions (Brewer and Charlet 1995) it has been concluded that "levels of naturally occurring resistance in sunflower germplasm are modest" (Brewer 1994). However, when adult insects are caged on field plants, more pronounced resistance has been observed (Table 4, Gao and Brewer 1998).

Table 3. Seed weevil resistant accessions and damage ratings. (After Brewer and Charlet 1995)

Accession	Ave. # of larval exit holes/head (visually detected)	Total # larvae/head (x-ray detected)
HA 894	56	69
431525	43	56
431537	42	56
251465	45	69*

*Had significantly higher number of larvae per head than HA 894

Table 4. Seed weevil resistant accessions evaluated by caging beetles on field grown heads (after Gao and Brewer, in press, 1998)

Accession or hybrid	n	Damaged seeds
431506	10	72.4a
HA 894	10	66.6ab
170417	9	44.6bcde
480471	8	31.8cde
253417	9	22.1e

Means within columns followed by the same letters are not significantly different ($P<0.05$)
Damage scored by observing exit holes and inspecting opened seeds

Miller (unpublished) has taken eight lines of PIs thought to have some resistance to seed weevil (Brewer, unpublished). Some of these lines flowered at different times from those in the lines to be crossed, and so were excluded. Pollen was removed from the putatively resistant lines, and crossed with USDA 821 and USDA 89, both self- or modestly self-fertile lines. Seed from all crosses were bulked. Seeds were planted in the field and 500 plants selected for self-pollination. These selections were planted in an area near Leonard, ND, where seed weevil infestation was known to be severe. After physiological maturity, seed was evaluated for larval presence or damage by x-irradiation procedures and the 20 or 30 selections with the least amount of larval weevil infestation were advanced to a second evaluation. A second cycle similar to the first is in progress.

c. Selection for resistance to sunflower beetle

Three separate approaches have been taken by Roseland and colleagues to find resistance to feeding by sunflower beetle. The first was to find existing mechanisms of chemical defense. If an identified sunflower defensive constituent could be found, it might be enhanced by appropriate crosses with wild and cultivated *H. annuus* to express it at higher concentrations. The second approach was an attempt to find a new chemical constituent that correlates with non-preference to feeding using inbreds and hybrids. Selection for this constituent in various sunflower sources would provide germplasm that deterred feeding of sunflower beetle. The third was developing a selection technique from among mutagenized sunflower to identify lines likely to contain high levels of feeding deterrent.

1. Survey of *Helianthus* accessions for high coumarin content: an induced resistance

The first approach was to identify specific chemicals that had deterring effects on insect feeding and that could easily be measured. In some plants, a correlation between chemicals that are bioactive on pathogens as well as bioactive on insects has been demonstrated, but this correlation has not frequently been documented. The coumarins scopoletin and ayapin have been shown to interfere with the growth of nonpathogenic fungi that invaded sunflower (Tal and Robeson 1986a). The important pathogenic fungi, however, actually degraded the coumarins (Tal and Robeson 1986b), so the activity of the coumarins is removed by the pathogens in order to allow maximal virulence. We began to analyze the direct effects of coumarins on insect preference, and in fact, showed that coumarins applied to sunflower leaves resulted in antixenosis of the treated leaves towards beetles compared to controls (Olson and Roseland 1989). Interestingly, the coumarin formed in plants steeply increased after wounding, insect feeding, fungal infestation and other types of damage to the plant (Tal and Robeson 1986a, Olson and Roseland 1989, Roseland and Grosz 1997).

The next step was to investigate sources of plants that might have elevated concentrations of coumarins. An obvious source were the wild species of sunflower. With Gerald Seiler, we picked out a number of species of *Helianthus* and showed that some indeed, such as *H. petiolaris*, had high concentrations of expressed coumarins in leaves. Unfortunately, when progeny of crosses (by Seiler) of *H. petiolaris* with cultivar quality sunflower were analyzed by HPLC, none

of these progeny had high concentration of coumarins (Roseland and Seiler, unpublished). From this work, it appears that interspecific crosses are not good sources for this type of resistance.

A source of genes for high coumarin production was also sought in various *H. annuus* accessions. We surveyed the content of 112 accessions of *H. annuus* from various parts of the USA (Roseland and Grosz 1997). A number of these had high concentrations in unstimulated plants, and others had high concentrations following stimulation (Table 5). These suggested that some of these might be useful in resistance of sunflower were they to be incorporated into high yielding cultivars. Unfortunately, after many of the lines were surveyed for coumarin content, they were not available from the sunflower USDA-ARS Plant Introduction Station in the following seasons for bioassay of activity against beetles. We also decided to investigate the relative importance of this single constituent as a source of deterrence to sunflower beetle.

Table 5. Range of scopoletin concentrations in stimulated wild accessions (selected examples) (After Roseland and Grosz 1997)

PI accession	Scopoletin (ng/mg) (mean)	Stimulated increase over unstimulated plant (fold)
413137	2.6	5.7
413034	10.2	17.4
413105	20.9	9.7
413153	60.3	26.2

Is coumarin itself a deterrent of uniform importance when it occurs in a variety of backgrounds? A regression analysis presumably would show a dose-response relationship of coumarins to feeding antixenosis. Feeding bioassays of eleven diverse lines along with an HPLC analysis for coumarin content were accomplished (Roseland and Grosz 1997). We should note that there was a large difference in the backgrounds of the lines that were assessed, being from various parts of the country, and from areas where various *H. annuus* subspecies were commonly collected. The content of coumarin and consequent insect deterrence were shown not to form a precisely linear relationship. This result might have been expected, since the expression of any gene will be affected by the environment in which it is expressed. Most of the eleven cultivars analyzed did show a relationship between increased coumarin expression and deterrence when analyzed by a new procedure, which was a comparison of changes in coumarin content and with changes in feeding scores that were measured following stimulation by chemically-induced stress (Roseland and Grosz 1997).

From the foregoing results, it was clear that increased coumarin concentration was usually correlated with a deterrence to feeding, but not always. Therefor, a strategy for finding plants with maximal expression of coumarin could identify lines resistant to sunflower beetle. However, this strategy may also require stimulation of coumarin expression before insects arrive, since the deterrence may not be built up rapidly enough in many populations of sunflower (Table 6 [Olson and Roseland 1991; Xu 1998]).

Table 6. Decline in leaf area consumed in *second pair* of leaves of hybrid IS 3311 plants on which beetles fed on the *first* pair of leaves on day 0. (After Xu 1998)

Interval from feeding stress	Decline in consumption relative to control (% leaf area less than control)	Significant
1d	19	no
3d	38	yes
5d	42	yes
7d	27	yes
9d	8	no

2. Selecting inbred and hybrid lines for chemicals which correlate with deterrence

A second source of resistance was sought through discovery of new chemicals that conferred or were related to resistance. There were no substantial sources of resistance to sunflower beetles, so we endeavored to come up with a new strategy for using modest differences in preferences that might be clues for chemically-based resistance. That is, if one could find a series of sunflower lines that could be ranked for preference it might be possible to find some chemical whose concentration paralleled that found in the preference series. While this chemical might itself be responsible for resistance, it only need correlate well with resistance to allow the selection of new plants that expressed these chemicals.

We ranked a series of inbreds and hybrids for relative feeding preference (Table 7 [Satter 1996]). Next, we used HPLC to survey for one class of likely deterrents, the phenylpropanoids. If high and low content for any single peak correlated with the preference relationships between lines, then it was a candidate for having deterrent activity. We found two peaks which showed a relationship between increases of the chemical and increases in deterrence. Thus, a mechanism is available for selecting plants for high sunflower beetle resistance. Lines with high expression of one or both of these chemicals will be good candidates for resistance to sunflower beetle. This relationship needs yet to be validated; if another series of lines is chosen, can deterrence be predicted from the quantity of the key deterrence-associated peaks?

Table 7. Ranking of selected hybrids for sunflower beetle feeding (after Satter 1996)

Line	Leaf Area Consumed (cm^2)	Significance (F-test)
RHA 274	11	yes
ARG 420-1	10	yes
HA 89	8	yes
ANO 1509	5	no
HA 303	4	no

Table 8. Relationship between phenolic content (x) and beetle feeding (y): Regression (after Satter 1997)

For HPLC peak eluting at 21.4 minutes:

$y = -1.61x + 1.45$
$r^2 = 0.46$
$n = 9$

3. Screening for resistance in mutagenized sunflower lines

The third approach taken made use of mutagenized lines of inbreds as sources for resistance to sunflower beetle. First, a chemical criterion was chosen to begin to screen up to 1000 mutagenized plant lines. Later, the selected plants would be analyzed for beetle feeding preference. Again, we have chosen to focus on the phenylpropanoids as a key class which should contain many potential deterrents. In the first stage of this assay we screened the available mutants for those which contained generally elevated phenylpropanoids. Leaf tissue was removed and crushed in a well slide and then assessed for reactivity with a phenylpropanoid-selective colored reagent, Prussian Blue (Stolzenberg and Roseland, unpublished). All wells with highly developed color were identified, and the corresponding line saved for replication (Table 9).

The next season (1996) the lines were grown in the field and increased for assays. The following season (1997), we grew the lines in the greenhouse, and did comparative feeding assays on them. The seven top lines showing at least 40-70% reduction in feeding were chosen from among the 35 on which we did feeding analyses. The next step is to again replicate the most promising lines, and then with sufficient seed, assess them in the field. If the differences in feeding are sufficient, these may be sources for resistant germplasm. Mutagenized lines appear to be a good pool from which to select resistance to sunflower beetle.

Table 9. Selection of mutagenized sunflower: first level screen. (After Roseland and Stolzenberg, unpublished, 1996)

Parent Line	Agent*	Concen (%)	No. Pruss/Blue Test	Phenolic level (# hi)	UV Response
HA 32	EMS	0.2	108	6	5
	NMU	0.1	201	10	0
		0.2	495	58	28
HA 821	EMS	0.2	51	0	0
Total			855	74	33

*EMS= ethyl methane sulfonate, NMU= N-methyl urea

d. Breeding for banded sunflower moth resistance

Sources of resistance to banded sunflower moth, *Cochylis hospes*, have been demonstrated in several non-*annuus* species (Charlet and Brewer 1995). Antibiosis was demonstrated in five species when eggs were placed on early bud-stage heads. Reduced preference of banded moth for oviposition on two species of *Helianthus* were also shown. Charlet, Brewer and others have also found some resistance in wild accessions of *H. annuus* (Table 10, [e.g., Jyoti 1998]).

Table 10. Mean number of seeds damaged by banded moth larvae following artificial infestation of heads in greenhouse. (after Jyoti 1998)

Accession/hybrid	Mean no. damaged seeds	Significance
PI 172906	70	b
PI 195945	49	b
PI 480471	44	b
Ames 3291	54	b
RHA 894	105	a

J.F. Miller (USDA-ARS, Northern Crop Research Lab, Fargo, ND) has begun to cross some of the resistant lines found in *H. annuus* accessions to high quality cultivars such as USDA 821 and USDA HA 89. This program and types of selections are similar to those discussed in the protocol for developing seed weevil resistance. Again, about 500 plants are grown in each generation, and 20-30 are selected for reduction in visible banded moth damage to the sunflower heads. Two generations have been selected.

Conclusions

At present there are no specifically developed commercial sunflower hybrids that may provide significant resistance to insects. Selection for resistance in collections of accessions and subseqent breeding techniques by classical means has begun as we have demonstrated. High agronomic quality lines are being developed for resistance to sunflower midge, banded sunflower moth, red sunflower seed weevil and to sunflower beetle, but the final releases of these may be years away. After the efficacy of these potential lines is determined, there will be a substantial period needed for adjustments to be made before their incorporation into an integrated pest management program. The need for these adjustments are a consequence of the possible alteration of the whole complex of pests and beneficials. Potentially, changes in some cultural practices may need to be made to accommodate any new lines that may be developed.

While germplasm sources of resistance present future possibilities, there are now available some technological tools by which lines could be improved to express insect resistance. If commercial companies or federal seed breeders have developed several equivalent lines for agronomic performance, or for fungal resistance, the potential of these lines for some types of insect resistance could be concurrently evaluated. Use of these technologies could guide the release of improved lines for better resistance against insects, enhancing the original focus of the variety

development. These techniques could be accomplished without directly assessing insect resistance in the field, but rather by analyzing some property of the plant itself for its predictive value in insect resistance. Sunflower beetle resistance could be evaluated in plants at the first leaf pair by HPLC analysis of the coumarin content. Soon we expect that an evaluation of phenylpropanoids measured by HPLC may be an even more accurate and general method for predicting resistance to sunflower beetle. Sunflower midge resistance can be evaluated by injection of 2-4-D into 4-5cm buds, since tolerance to the auxin indicates a tolerance to larval midge infestation. These techniques could easily be built into the normal process of routine development of sunflower seed.

A focus of sunflower resistance research should also include prospective new strategies to find additional plant resistance to insects. The induced responses of sunflower that arise against insect infestations have begun to be demonstrated; these may become the basis for new strategies that protect plants against insect pests. With the development of appropriate protocols and inducers, a highly specific defense of plants could be initiated. In the interim period before classical strategies help develop resistant plants, a strategy of discovering these induced resistant responses in sunflower to various insects should be made.

At present, some of the induced responses of sunflower can be shown after sunflower beetles feed on leaves (Olson and Roseland 1991; Xu 1998). Deterrence can be provoked by chemical stress, such as that of applied heavy metals (Roseland and Grosz 1997) and by methyl jasmonate (Peterson and Roseland, unpublished), and possibly by other types of endogenous regulators of plant defenses, such as salicylic acid (Roseland and Grosz 1997). While commercial interests are developing many analogues to these natural coordinators of resistance, a selection of lines that lead to maximal responses of these regulators will need to begin. A strategy employing an inducer of defenses, and an easily inducible host has the advantage that defensive responses can be initiated at the most efficacious time. Insects will presumably not become resistant to this strategy since the selecting agent will not be continuously present at selecting levels. Resistance to sunflower insects can take many potential directions, and perhaps all of them should continue to be explored; just as wild plants have many defenses, so also perhaps, should the selected varieties of cultivated plants.

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Integrating the Management of Sunflower Pests

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Integrated Pest Management

Integrated pest management (IPM) has a broad genesis. Following World War II much of insect pest management focused on insecticidal control. Insecticides were seen as a panacea and it was thought by many that the golden age of insect control had arrived. However, it wasn't long before negative aspects of insecticides became apparent and pesticide use and misuse were a focal point of a burgeoning environmental movement. At the same time pest control practitioners and researchers were becoming concerned by outbreaks of secondary pests and by increasing development of insecticide resistance in insects. These and other factors led to the development of a new pest control paradigm, integrated pest management. IPM is ecologically oriented pest management; it uses biologically based controls that optimize, on a long-term basis, the costs and benefits of crop production.

Any number of definitions of IPM can be found, but they are similar and they share certain characteristics. IPM promotes minimized pesticide use, enhanced environmental stewardship, and sustainable systems, and integrates a number of management tactics. In theory IPM is centered around the use of natural enemies, plant resistance to insects, and cultural controls to maintain pest populations below damaging levels. Chemical controls are not excluded, but are used only if other methods are insufficient. The philosophy is to manage a pest rather than eradicate it (hence, IPM).

IPM is:

- a method of estimating the risk poised to a crop by insects,
- a strategy of pest containment that seeks to maximize the effectiveness of biological and cultural control factors, utilizing chemical controls only as needed and with a minimum of environmental disturbance,
- an ecologically based system in which all available techniques are evaluated and consolidated into a unified program to manage pest populations so that economic damage is avoided and adverse side effects on the environment are minimized.

As an ecologically based pest management system, the objectives of IPM are to maintain profitability by using controls only as needed, to minimize selection pressure on pests, and to minimize environmental impact. While the objectives of IPM are clear, the practice of IPM is difficult. IPM is based on sound scientific principles with refinements resulting from research. A large knowledge base is necessary. An insect's behavior, life cycle, and interaction with its host needs to be throughly understood before ecological pest management can be developed. Sufficient expertise is needed to develop, implement, and improve pest management systems. Knowledge is

needed in a number of areas and is beyond the scope of any individual. Depending on the problem being considered, expertise in population dynamics, sampling, insect pathology, plant-insect interactions, and chemical control are required. In addition, there is often a need for expertise in plant pathology, plant breeding, and genetics. Another drawback to the successful implementation of IPM is an expectation of a panacea, a "silver bullet", that will solve the problem.

IPM tactics can be classified into two general types, preventive and responsive. Preventive tactics seek to prevent or delay the development of damaging insect populations. Cultural controls (such as, planting dates, sanitation, and crop rotation), plant resistance to insects, and biological control are preventive tactics. The goal of preventive tactics is to avoid a problem by modifying the insect's environment so that it is less favorable to the pest's growth and development.

Responsive IPM employs intensive monitoring and usually, the judicious use of pesticides. The tactics used seek to reduce the size of a too large insect population. Responsive controls should be implemented **only when** the insect population is at or is expected to reach a damaging level. To determine if the population warrants a responsive control, it is necessary to sample the insect population and estimate crop risk. Sampling is not simple and may involve counts of insects or indirect measurements of their activity, such as leaf defoliation. However the sampling is done, it is essential to be able to relate the sample density to plant injury. In other words, how many insects per plant or per area or how much defoliation will lead to a given level of injury and what is the value of that injury. Once these variables are known, an economic injury level (EIL) can be set. The EIL is the insect density at which the cost of a responsive control is equal to the value of crop loss due to insect damage. The EIL is a tool to make an objective decision, it asks the question, is action needed? And if so, what should be done?

The EIL integrates crop value and management costs with biological information on the relationship between pest injury and yield. It is essential for rational pest management decisions.

Sunflower Insect Pest Management

In the Northern Great Plains, sunflower has five key insect pests. These are: the sunflower beetle, *Zygogramma exclamationis* (Fabricius), the sunflower midge, *Contarinia schulzi* Gagné, the sunflower stem weevil, *Cylindrocopturus adspersus* (LeConte), the red sunflower seed weevil, *Smicronyx fulvus* LeConte, and the banded sunflower moth, *Cochylis hospes* Walsingham. Pest management systems for these insects are in varying degrees of development.

Sunflower Beetle. Parasitoids attack all stages of the sunflower beetle. They include *Erixestus winnemana* Crawford, an egg parasitoid, *Miopharus macellus* (Reinhard), a larval parasitoid, and *Myiopharus* sp. an adult parasitoid. Predators include a number of general predators such as coccinellids, pentatomids, and the carabid, *Lebia atriventris* Say, that feed on both eggs and larvae. However, methods to enhance the activity of sunflower beetle natural enemies are lacking. Pest management largely relies on the responsive use of insecticides. Sampling is done using a basic X pattern. Several economic thresholds based on adult (1 to 2 per seedling) or larval (10 to 15 per plant) counts or percent defoliation can be used to make

treatment decisions. If a treatment is warranted, there are a several effective insecticides available.

Sunflower Midge. Pest management tactics for the sunflower midge are less developed. Certain cultural controls may help lessen damage. Planting away from areas where high midge populations were experienced the previous year may decrease the midge population in the current year's field. Midge infestation can occur throughout the bud stages and as a consequence sunflower is vulnerable to infestation for about a two week period. If several fields are being planted, it is suggested that the planting dates be staggered so that not all fields are in a susceptible stage if a high midge population develops. A low level of resistance or tolerance exists in some commercial sunflower hybrids. If there is a possibility of a damaging midge population, the most tolerant hybrid that fits other agronomic needs should be planted. Currently, there are no responsive controls available.

Sunflower Stem Weevil. Little physiological yield reduction is caused by the sunflower stem weevil. Most economic loss occurs when plants lodge as a result of larval activity in the stems. Both preventive and responsive tactics are available for the sunflower stem weevil. A number of natural enemies are identified but how to increase their impact is not known. Cultural controls include stalk management to decrease the overwintering population and late planting to avoid the adult weevil's peak oviposition period. Agronomic practices, such as low plant populations, that result in large stem diameter make sunflower less susceptible to lodging. Chemical controls may be either preventive at planting time or responsive foliar applications. Preventive, planting time applications of insecticides are made without knowledge of the sunflower stem weevil population density and thus are often not needed. For responsive control, an X pattern is used to scout for adult weevils and an economic threshold value is used to help determine if control is needed.

Red Sunflower Seed Weevil. Probably more effort has been made to develop pest management options for the red sunflower seed weevil than for the other sunflower pest insects. Cultural controls such as tillage and planting dates can help reduce the number of weevils in fields. Responsive chemical control is based on an economic threshold and scouting using a sequential sampling plan. Sequential sampling can be simpler and is more accurate than the X pattern sampling used for most sunflower insects. For chemical control of the red sunflower seed weevil, timing of insecticide treatment is critical. Treatment should be taken before too much egg laying has occurred, yet after most weevils are in the field. A trap cropping system with both cultural and chemical control elements is available. Moderate sources of resistance have been found in sunflower accessions. These are being used to develop resistant germplasm.

Banded Sunflower Moth. The banded sunflower moth is a common pest in North Dakota and Minnesota and a potential pest in Kansas, Colorado, and Nebraska. Damage caused by the banded sunflower moth can be minimized by planting late (early June) to avoid the peak oviposition period. Deep fall plowing of sunflower stalks can reduce moth emergence the following season. Natural enemies can have a large impact on the banded sunflower moth. Eggs and young larvae are preyed upon by generalist predators and larvae are attacked by a number of parasitic Hymenoptera. Ground beetles were found to destroy about 40% of overwintering larvae and pupae. At times however, responsive controls are needed. Sampling is done by counting

moths on 20 plants per sample site. Five sample sites in a X pattern are made throughout the field. A calculated economic threshold is then used to determine if insecticide treatment is needed. Insecticide efficacy is maximized if application timing is based on the plant developmental stage. Chemicals applied to sunflower at the late bud stage to pollen shed initiation significantly reduce banded sunflower moth damage, whereas insecticides applied to sunflower 2 weeks later failed to reduce damage. Resistance to the banded sunflower moth has been identified but resistant germplasm is not yet available.

Implications of IPM Recommendations

Pest management recommendations need to evolve as cropping practices change. A major trend in agriculture is the movement to reduced and no-tillage systems. The crop residue left on the soil is of great benefit in reducing soil erosion and in water management. However, the residue can be a harborage for pests and may be attractive to certain insects, such as cutworms. A trend in sunflower is to switch from the traditional 30" row spacing to narrower row spacings. The impact of this change on sunflower insects and other pests is not yet known.

In some cases pest management recommendations may conflict. For example, it is recommended that a late planting date be used to minimize banded sunflower moth infestation. This helps by having sunflower pass the susceptible stage for oviposition before most moths have emerged. However, late planting is likely to maximize red sunflower seed weevil damage. The red sunflower seed weevil emerges later, utilizes the crop later in its development cycle, and is very mobile, moving from site to site to find susceptible sunflower. If a location has both pests, planting date may help for one insect but may increase the damage caused by the other.

Sorting out how insect pest control recommendations may conflict with each other, how they may conflict with disease and weed pest management, and how they interact with agronomic practices has been left up to the grower. The complexity of the interactions quickly becomes overwhelming. A truly integrated crop management system would take into account insects, disease, weeds, and agronomic practices.

Do we have IPM?

Yes, in the sense that we are using the best available technology and that technology is being evaluated and modified. Yes, in that when responsive controls are needed, insect damage is related to injury and EILs are available.

But on the other hand we do not have IPM in the sense that pest control is almost entirely dependent on insecticides. Preventive controls are not in place or are not very effective and pest management is almost entirely based on the use of insecticides as a responsive treatment. Sunflower IPM is not integrated among the insects and among insects, pathogens, and weeds it is even less integrated. Recommendation interactions are often not fully considered.

However, there is potential for true integrated pest management in sunflower. Many IPM components have been developed or are near fruition. We know of many natural enemies but

more work is needed to develop tactics to conserve and enhance their effectiveness. Sources of resistance are known and are being developed as germplasm. For most of the major insects pests we do have valid sampling plans and EILs. We know the impact of various cultural practices. What is lacking is an integration of the various recommendations and practices, the elucidation of weaknesses, and the development of a method for comparing pest management and production options to maximize sustainable production.

Sunflower Integrated Pest Management: A Proposal

To ensure that in the future pest management in sunflower is truly integrated and that sunflower protection is ecologically based and sustainable, Larry Charlet and I propose that an IPM Advisory Group be established. This group should consider issues of true integration of control tactics and production practices. It should consider pest management needs and make recommendations. The objectives of the group would be to review the overall status of sunflower pest management, not just insect pest management, to make direction and policy recommendations to the National Sunflower Association, and to encourage research in directions as appropriate. Ideally it should consist of pest management researchers, industry personnel and sunflower producers. A sunflower IPM advisory group could be a model for other crops and be of real benefit to sunflower production and industry.

Funding Opportunities for Sunflower IPM Research

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Funding for agricultural research has become successively harder to obtain. Recent federal cutbacks in recurring federal funding have decreased the amount of money available to agricultural researchers in many states ($750,000 in Minnesota alone). Many of these federal dollars have been redirected to federal competitive grants programs. However, a number of granting agencies have, in recent years, decreased the funding available to entomology programs. In addition, a greater number of researchers are being encouraged to pursue competitive funding to fulfill job and tenure requirements. The end result is a smaller pool of research dollars with greater competition that makes funding for entomology more difficult to obtain.

Successful grants have always been those which have been well-prepared and targeted towards a specific funding agency. With increasing competition, it has become even more important to address those issues that lead to favorable review. There are a number of common features among recently successful grants in agricultural entomology:

1. Limit the study's time period to a reasonable length. It is becoming increasingly more difficult to obtain funding for long-term projects (longer than 3 years). If the project is one that can only be answered with long-term research, many authors successfully divide the project into a series of shorter-termed, funded proposals.

2. Proposals should have a broad scope, addressing more than one simple objective (unless it is a one-season study). At the same time, it is essential that proposals have clearly stated and well thought out objectives. An attempt should be made to strongly link theory to practice in proposals targeted to funding agencies dealing with agriculture.

3. Potential economic benefit is becoming increasingly important to funding agencies. Many proposals now require a section outlining the benefit the research will have to the commodity and the region.

4. Proposals should be prepared with great care and attention to detail. The need, objectives, and methods should 'flow'. There should be no doubt among the review panel that the proposal is in the best interests of the region; that the problem is one of sufficient magnitude that it requires attention, and that the objectives and methods provide the best alternative of

answering that problem. It is also desirable that the project has a high chance of success.

One method of ensuring these factors are met is by targeting grants to specific funding agencies. In targeting a project for submission to a specific funding body, there are a number of factors to be considered. The project type (e.g. research, extensions, equipment, personnel, etc.) is the primary consideration. Many funding agencies have monies available for limited types of projects. Grant programs are frequently limited in the size of grant they will award. The budgets of successful proposals should be within these 'comfort zones'. A further consideration is the term of the grant. Most competitive grants are limited in the length of time for which they will award funding. A submitted proposal must be able to be completed within this term.

The 3 most common categories of funding agencies to which researchers can apply are commodity and industry groups, state agencies, and federal agencies.

In sunflowers there are a number of commodity groups (e.g. National Sunflower Association and the High Plains Sunflower Assoc.). The comfort zone for commodity funding is generally less than that of state or federal programs but their proposals also usually require less preparation. Projects funded by these groups tend to be short-term (1-2 seasons), individual grants, ideal for simple research or extension projects.

State funding obviously varies by state and the funds available depend on the state economy. Often state grants are linked to federal programs and cooperative agreements and they frequently require matching funds from a non-state source. State programs are also more likely to be responsive to regional and local needs. Some examples of state funding in Minnesota include the Legislative Council on Minnesota Resources (LCMR), Minnesota Institute of Sustainable Agriculture, and the Agricultural Utilization Resource Institute (AURI). The LCMR program is open to all Minnesota residents and concentrates on conservation of natural resources but will fund agricultural projects which accomplish these results. They have a 2-year term and a comfort zone that varies from \$20K - >\$100K per year. Proposals submitted to LCMR must have a significant impact on regional economies and are highly political. The AURI program of interest to sunflower entomology is their Pesticide Reduction Options (PRO). AURI-PRO proposals must be submitted by a commodity group (i.e. university and government researchers cannot directly apply). They are 1-2 year grants with a \$30K cap and require non-state matching funds. An ideal strategy is to combine commodity funding with AURI proposals. The AURI-PRO program has an open deadline with proposals being accepted throughout the year.

Federal funding programs for agriculture are mostly under the Cooperative State Research Education and Extension Service (CSREES). There are numerous programs: National Research Initiative (NRI), Regional Integrated Pest Management (Regional IPM), Sustainable Agriculture Research & Education (SARE), National Agriculture Pesticide Impact Assessment Program (NAPIAP), and the Alternative Pest Management program. These are usually directed at university and government researchers and have

different terms and funding levels. The NRI program is probably the most competitive funding source for agricultural research in the country with only 11% of submitted proposals being funded. They are peer-reviewed, require high scientific merit, preliminary data, and do not require matching funds. The NRI proposal is long (usually >30 pages) and must be very well prepared and written but the funding levels are substantial (~$60k - $100K per year for up to 3 years). The Regional IPM program is less competitive than the NRI but is still peer-reviewed and successful proposals must be carefully prepared. They are generally regional, applied projects and can be either extension or research related. Higher funding levels are available for research grants (up to $75K compared to up to $20K for extension projects), are up to 2 years in term and do not require matching funds (although they are considered helpful). Regional IPM proposals that are cooperative arrangements between institutions or states and those that cross disciplines are well received. The Regional IPM proposals are moderate in length (~15 pages) and require a letter of intent to submit before the actual proposal is submitted. The SARE program is designed to fund regional, very applied research (theoretical work is outside the scope of this funding program). There are a number of different categories including Research and Education (R&E), Agriculture in Concert with the Environment (ACE), Producer grants, and Professional Development grants. They are peer-reviewed, and the various categories have different funding levels, although R&E grants have a term of up to 2 years and are funded at levels of $30K-$200K. All categories require matching funds. The NAPIAP grants concentrate on pesticide use and again there a number of different categories. They are peer-reviewed, short proposals (~6 pages) have a term of 2-3 years and are funded at $10K-$30K per year. Matching funds are not required but are encouraged. NAPIAP projects require Good Lab Procedures (GLP). This requires lab staff to be GLP trained. There are a number of other USDA grant programs (e.g. higher education grants for sponsoring and supporting students, Alternative Pest Management, and Inter-Regional 4 to assist in registering pesticides and biological controls for minor crops). Information on USDA-CSREES granting programs can be found on their WWW site at: http://www.reeusda.gov/programs.htm.

The requirements and characteristics of the different funding agencies allows us to formulate some potentially useful strategies. Because many of the grants require or encourage matching funds, commodity and state grants can often be used to leverage funding for larger projects. Even if matching funds are not required, prior funding on a project is often useful. Funding agencies are more likely to support a project if it has already been funded by another agency; it is one way in which they can fund projects they could not otherwise support on their own. Unlike state programs, federal funding agencies prefer to fund those projects which are regional, especially those with principal investigators from different states and/or institutions. Proposals which cross discipline boundaries are also well received (IPM standing for *Integrated* Pest Management, not Insect Pest Management). Consequently, efforts should be made to design the project to incorporate questions from other disciplines or to include researchers from neighboring states. If possible, partnering with industry may also offer some advantages in obtaining funding from federal agencies. Finally, the proposal

should be seen by the reviewers to be a good investment of research dollars. It should have a high potential for successful completion, which would bring a positive economic benefit to the region.